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SEDIMENT STUDY
OF PETROLIA RESERVOIR AND ITS DRAINAGE AREA

Petroleum and Fergus Counties, Montana

Prepared for the

Montana Department of Natural Resources and Conservation

by

STREAMWORKS

614 Hollins
Helena, Montana 59601

March, 1985

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ABSTRACT

In 33 years, Petrolia Reservoir (Petrolia County, central Montana) has accumulated sediment displacing 1100 acre-feet of storage space, a capacity loss of 12%. Raising the spillway by 21.4 feet would increase the present capacity of 8400 acre-feet to 23,300 acre-feet.

In the reservoir's south or Flatwillow Creek arm, 1 to 3 feet of silt, clay, and fine-grained sand mantles the bottom, and entirely fills the old creek channel. There are two deltas, an upper, well-developed one and a lower, poorly-defined one. The south arm has received 2.8×10^3 tons/square mile of sediment from a drainage area of 400 square miles. In contrast, in the west or Elk Creek arm, less sediment mantles the bottom and there are no obvious deltas, although the old channel is locally filled with sediment. The west arm has received 2.3×10^3 tons/square mile of sediment from a drainage area of 212 square miles. Mean annual sediment yield to the reservoir is 85 tons/square mile/year.

Soil erosion problems occur chiefly in the semiarid lower half of the Petrolia watershed, where there are extensive areas of shallow, infertile, locally saline soils underlain by the Colorado and Claggett Shales. Sediment delivery to the reservoir probably occurs mainly during major runoff events. Heavy grazing on much rangeland has caused erosion problems, and on some croplands, no sod strips are left along drainage bottoms, and there is no terracing or contour ploughing. If these land use practices continue, heavy rains or rapid spring melt-offs will probably cause severe water erosion. Long-term monitoring of erosion rates and sediment yield on selected range and sod-busted sites is recommended.

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SUMMARY

In the 33 years since its construction, Petrolia Reservoir has accumulated sediment weighing 1.6×10^6 tons and displacing 1100 acre-feet of storage space below a spillway elevation of 2898.6 feet. This is a loss of 12% of the total storage capacity of the reservoir. The reservoir sediment has a mean dry specific weight of 67 lb/cu ft. The sediment consists largely of silt and clay, with minor fine sand and gravel. Plate 3 shows the thickness of reservoir sediment.

The total storage capacity of the reservoir (elevation 2898.6) is now 8400 acre-feet, as calculated from an elevation-area curve derived from planimetering a topographic map (plate 2) of the reservoir pool. If the spillway were raised to 2920 feet, the capacity would increase by 280 % to 23,300 acre-feet.

The bulk of the sediment occupies the upper south arm of the reservoir, which receives the flow of Flatwillow Creek. There, the pre-reservoir alluvial channel is entirely filled with silt, clay, and fine sand that form two deltas, an upper, well-developed one and a lower, poorly-defined one. The upper delta has built up from approximately 2892 to 2899 feet, just above the high pool level; the upper surface of this delta is colonized by a dense willow thicket. The lower delta was deposited between approximately 2877 and 2882 feet, and remains submerged except during dry years when the reservoir is drawn down. Reservoir sediment is more than ten feet deep in the upper delta, but only 5 to 7 feet deep in the lower delta.

A layer of sediment 1 to 3 feet thick mantles submerged alluvial terraces that flank the old, sedimented-in channel of Flatwillow Creek. In contrast, in the west arm of the reservoir, little sediment mantles the submerged terraces above the old Elk Creek channel; typically the sediment is only 0.5 to 1.5 feet thick, except in abandoned channels on the old flood plain, where sediment is commonly 2 to 5 feet deep. There are no obvious deltas in the west (Elk Creek) arm of Petrolia Reservoir.

The total weight of sediment in each of the arms of the reservoir is roughly proportional to the drainage area above each arm: The south arm contains 1.1×10^6 tons of sediment supplied by 400 square miles of drainage (or 2.8×10^3 tons/square mile). In contrast, the west arm contains 5.0×10^5 tons supplied by 212 square miles of drainage (2.3×10^3 tons/square mile). Assuming a 100% trap efficiency for Yellow Water Reservoir (drainage area 55 square miles), the west arm yield is approximately 3.2×10^3 tons/square mile. Mean annual sediment yield to the reservoir was 85 tons/square mile/year, plus or minus 34%.

Landuse in the Petrolia watershed is shown on plate 4. In the foothills and the upper half of the watershed are a patchwork of forestland and rangeland with scattered cropped fields. In the lower, semiarid half of the watershed are extensive terraces, low hogbacks, and rounded hills mostly used for range. Irrigation is extensive along valley bottoms while many unirrigated terraces and hillcrests are locally cropped, mostly with winter wheat.

There are many abandoned dryland fields, presumably plowed out and cropped during pre-dustbowl days. Much of the "sod-busted" land (see below) above Petrolia reservoir was actually this land broken to the plow, cropped for a time, then allowed to revert back to range.

Plate 5 shows areas of erosion problems and saline soils in the drainage basin above Petrolia Reservoir. These areas chiefly lie in the semiarid lower half of the Petrolia basin, where soils are shallow, impermeable, saline, or infertile. Much of the eroded sediment is temporarily stored at the base of slopes, on flood plains, or in small alluvial fans where minor tributaries enter the main stream valleys, rather than delivered to the main streams and thence to the reservoir. Thus, sediment delivery to Petrolia Reservoir probably occurs mainly during major runoff events, when the trunk streams erode their banks and channel bottoms, and when tributaries erode and transport sediment away from temporary storage sites. Wind erosion is severe on may cropped fields. This report does not evaluate wind erosion.

Plate 6 is a map of rangeland recently plowed, or "sod-busted", and planted to dry-land crops. There is no evidence for rapid or "accelerated" water erosion on this land during the past two years, since plow-out. In the sod-busted areas visible from main roads there are few sod strips left along drainage bottoms; no terracing or contour plowing is being used; and soils are relatively erodible. If current land use practices continue, it is probable that severe water erosion will happen in the future, during heavy rains or rapid spring melt-off.

Long-term monitoring of erosion and sediment yield on selected range and sod-busted sites, along with resurveys of reservoir sediment, are recommended to quantify the sediment yield to the reservoir, and the relationship to land use. Chapter 7 summarizes this proposed work.

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CHAPTER 1. INTRODUCTION

Petrolia Reservoir is located about seven miles southeast of Winnett, in central Montana east of the Big and Little Snowy Mountains (figure 1). Owned by the Montana Department of Natural Resources and Conservation, the reservoir is operated to store water for summer irrigation. The reservoir also supports a modest sport fishery. The Department is considering raising the dam and spillway crest to increase the storage capacity of the reservoir.

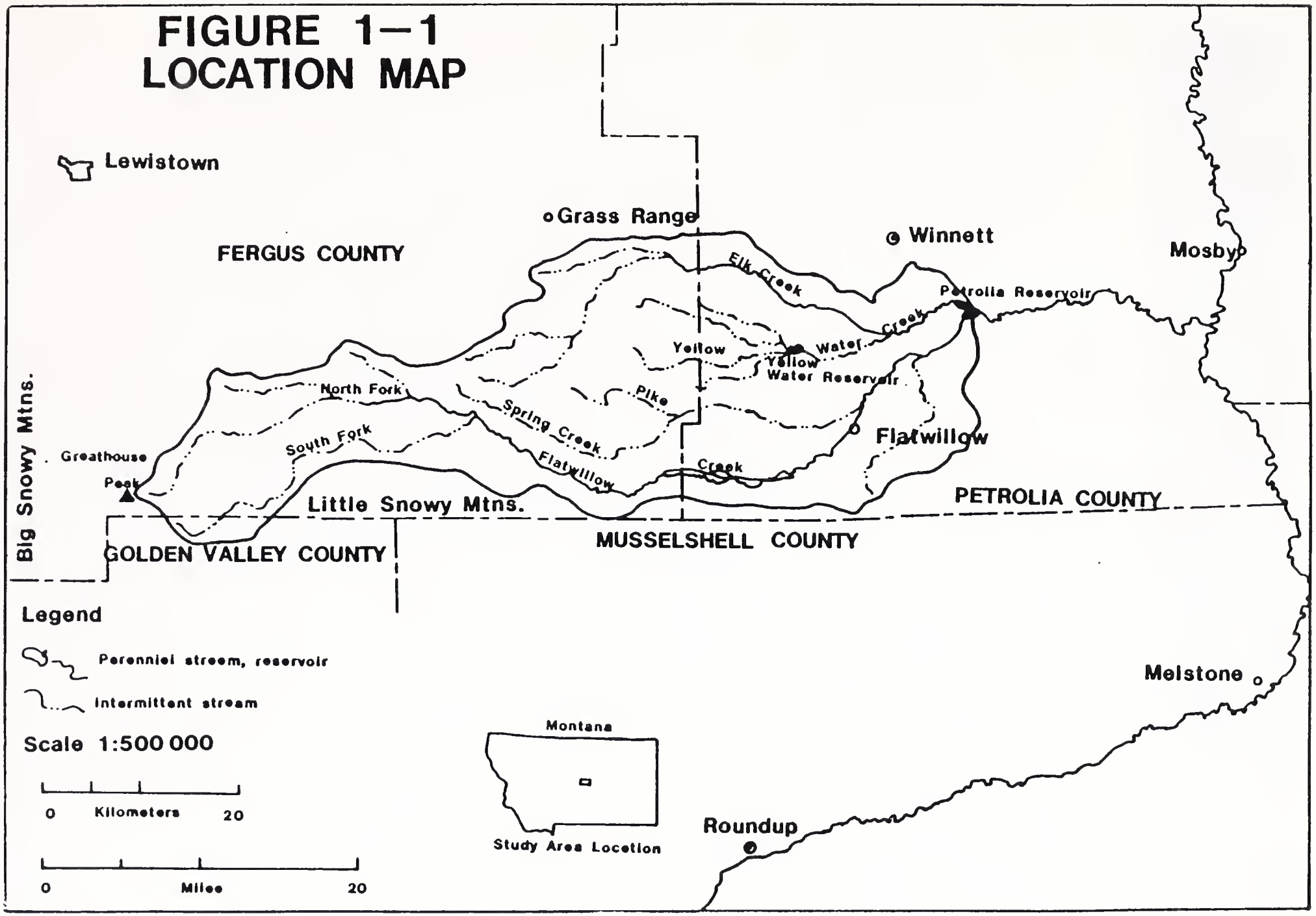
The reservoir presently has a storage capacity of 8380 acre feet and a surface area of 510 acres at the spillway elevation of 2898.6 feet (above mean sea level). The spillway elevation may be increased to approximately 2910 to 2920 feet. HKM Associates (Billings) is currently retained by the Department to make a technical evaluation of the proposed expansion of the reservoir.

The reservoir is shaped as an inverted "V", with a south arm of the reservoir extending up the valley of Flatwillow Creek, and a west arm extending up Elk Creek. Flatwillow Creek has a long narrow drainage basin, heading in the Big Snowy Mountains, while Elk Creek and its major tributary Yellow Water Creek begin in foothills (plate 1). The Flatwillow drainage above Petrolia has a relief of 6750 feet; the Elk Creek drainage 2350 feet, and the Yellow Water Creek drainage 1300 feet. The three streams flow east past low-lying, semiarid hills and terraces before reaching the reservoir. There are heavy irrigation withdrawals whose magnitude is not known. This low land above the reservoir is mostly underlain by the Colorado Shale, which typically weathers to produce shallow, relatively erodible soils. Cattle ranching and and dryland farming (mostly winter wheat), along with limited timber harvesting in the mountains, are the principal land uses in the Petrolia drainage.

Yellow Water Creek is dammed about six miles above its confluence with Elk Creek just west of State Highway 244 (plate 1.) Yellow Water Reservoir catches much of the runoff and sediment that otherwise would reach Petrolia Reservoir. For this reason, and because the Elk Creek-Yellow Water drainage area is only 212 square miles, in contrast to the much larger 400 square-mile drainage area of Flatwillow Creek, the south arm of Petrolia Reservoir has trapped much more sediment than the west arm.

This sedimentation report quantifies the loss of storage caused by buildup of sediment on the Petrolia Reservoir's bottom. The report also discusses the relation of land use in the upstream watershed to sediment yield to the reservoir, with special refer-

FIGURE 1–1
LOCATION MAP



ence to sediment yield from sod-busted (recently ploughed) rangeland. A companion report summarized in Chapter 7 presents recommendations for a long-term monitoring program to quantify both the sediment yield to the reservoir and the sediment budgets of sod-busted and control (rangeland) watersheds.

CHAPTER 2. HYDROGRAPHY

SURVEYING AND SOUNDING

A survey to establish horizontal and vertical control for topographic and hydrographic mapping was done by the Department and Streamworks during the summer and fall of 1984. The survey established baselines along the northern and eastern sides of the reservoir, with monumented transects (sediment ranges) extending at approximately right angles across the reservoir (plate 2). A total of 51 control points were established to define 34 transects for subsequent topographic and hydrographic mapping.

Key control points were targeted in August for aerial photography and reservoir mapping. Associated Surveys Inc. (Billings) prepared a 1 inch = 200 feet, 5-foot contour map of the exposed pool above el. 2878.4 feet. A 1 inch = 400 feet reduction of this map was used as a base for plotting detailed sounding and field survey information collected by Streamworks.

In June 1984, when the pool was at 2890 feet, 19 transects were sounded using an acoustic depth finder mounted on a boat. The bottom profiles were reduced and used to draw a topographic map of the sediment surface below an elevation of 2878 feet and to field check the photogrammetric mapping. Detailed topographic surveys of 15 transects located in the upper arms of the reservoir were performed in October 1984; field survey information in the upper southern arm (southwest of transect 6-S to 6-S-B), which is well vegetated, were also used in plotting the sediment surface contours shown in plate 2.

Plate 2 is a composite map incorporating the photogrammetric, hydrographic, and field survey information. Methods used in surveying, sounding, and preparing plate 2 are given in Appendix B.

RESERVOIR VOLUME

The volume of Petrolia Reservoir was calculated using two methods. Planimetry of the areas within five-foot elevation contours shown on plate 2 gave the information to plot an elevation-area curve for the reservoir (figure 2-1). The elevation-area method for determining reservoir capacity and average end-area methods (Vanoni

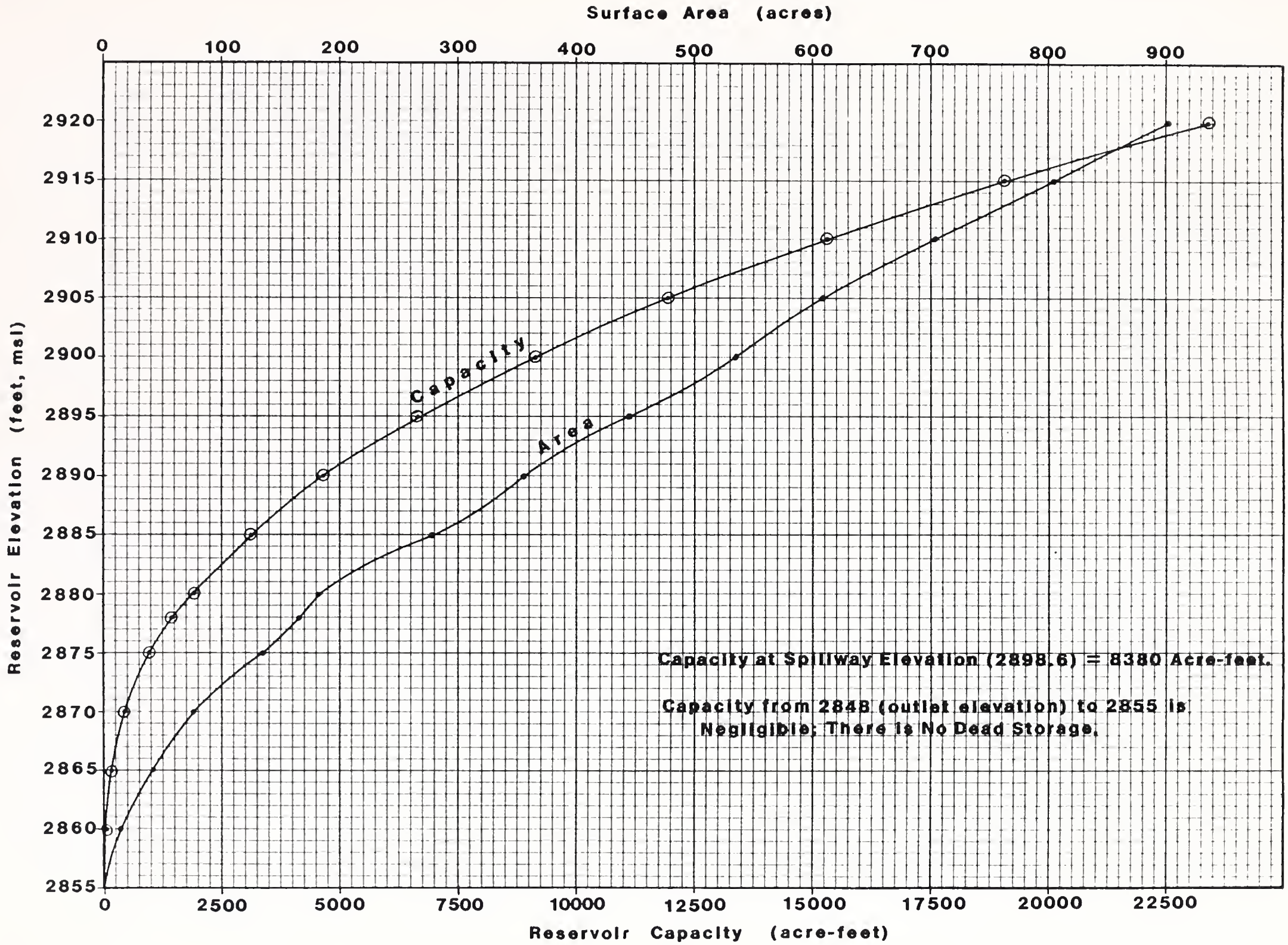


Figure 2—1. Area and Capacity Curves for Petrolia Reservoir, August, 1984.

Table 2-1

Petrolia Reservoir: 1984 Total Area-Capacity

Elevation Interval (ft Msl)	Total Area in Interval (acres)	Cumulative Area (acres)	Average End-Area (acres)	Elevation Interval Capacity (acre-ft)	Total Capacity (acre-ft)
2920-2915	94.7	902		4280	23300
			855		
2915-2910	101	808		3790	19100
			758		
2910-2905	97.8	707		3290	15300
			658		
2905-2900	73.9	609		2860	12000
			572		
2900-2895	88.5	535		2460	9120
			491		
2895-2890	90.9	446		2000	6660
			401		
2890-2885	76.0	355		1590	4660
			317		
2885-2880	61.7	279		1250	3070
			249		
2880-2878	51.9	218		380	1820
			192		
2878-2875	31.7	166		450	1440
			150		
2875-2870	57.2	134		530	987
			106		
2870-2865	36.0	76.0		295	457
			59.0		
2865-2860	29.0	40.9		132	162
			26.0		
2860-2855	11.9	11.9		30.0	30.0
			6.0		
2855-2850	0.0	0.0		0.0	0.0

(Capacity at spillway el. 2898.6 ft msl = 9120-740 = 8380)

1977; Heinemann and Dvorak 1965) gave comparable results. Elevation-area and area-capacity data for the reservoir are summarized in table 2-1 and figure 2-1.

At a spillway elevation of 2898.6 the capacity of Petrolia is 8380 acre-feet. Raising the spillway to 2920 feet would increase the capacity by 280% to 23,300 acre-feet. A log-log, least-squares regression of reservoir elevation against capacity is given in figure 2-2; the relationship is accurate within ±5% and has a coefficient of determination (r^2) of 0.94.

Area-capacity data calculated for the west arm (upstream from transect 3-W to 204), pool above dam (transect 3-W* to 204 and 2-S* to 204) and south arm (upstream from transect 2-S to 204) are given in Appendix F. The capacities of these areas, below an elevation of 2900 feet are given below (table 2-2).

Table 2-2

Distribution of Storage Capacity below 2900 feet,
Petrolia Reservoir

	Area (acres)	Capacity (acre-feet)
West Arm	261	4070
Pool	85	2550
South Arm	189	2500
TOTAL:	535 acres	9120 acre-feet

The west arm and the pool area account for about 70% of the remaining reservoir capacity.

A 1 inch = 400 feet map of the reservoir, prepared in 1945, was used to estimate the loss of storage since impoundment in July of 1951. The map was found to be too generalized for precise comparison with plate 2. The pre-impoundment (1945 map) and 1984 elevation-capacity curves are compared in table 2-3. If the 1945 information is correct, the loss in capacity is about 820 acre-feet at the spillway elevation.

* survey stations shown on plate 2

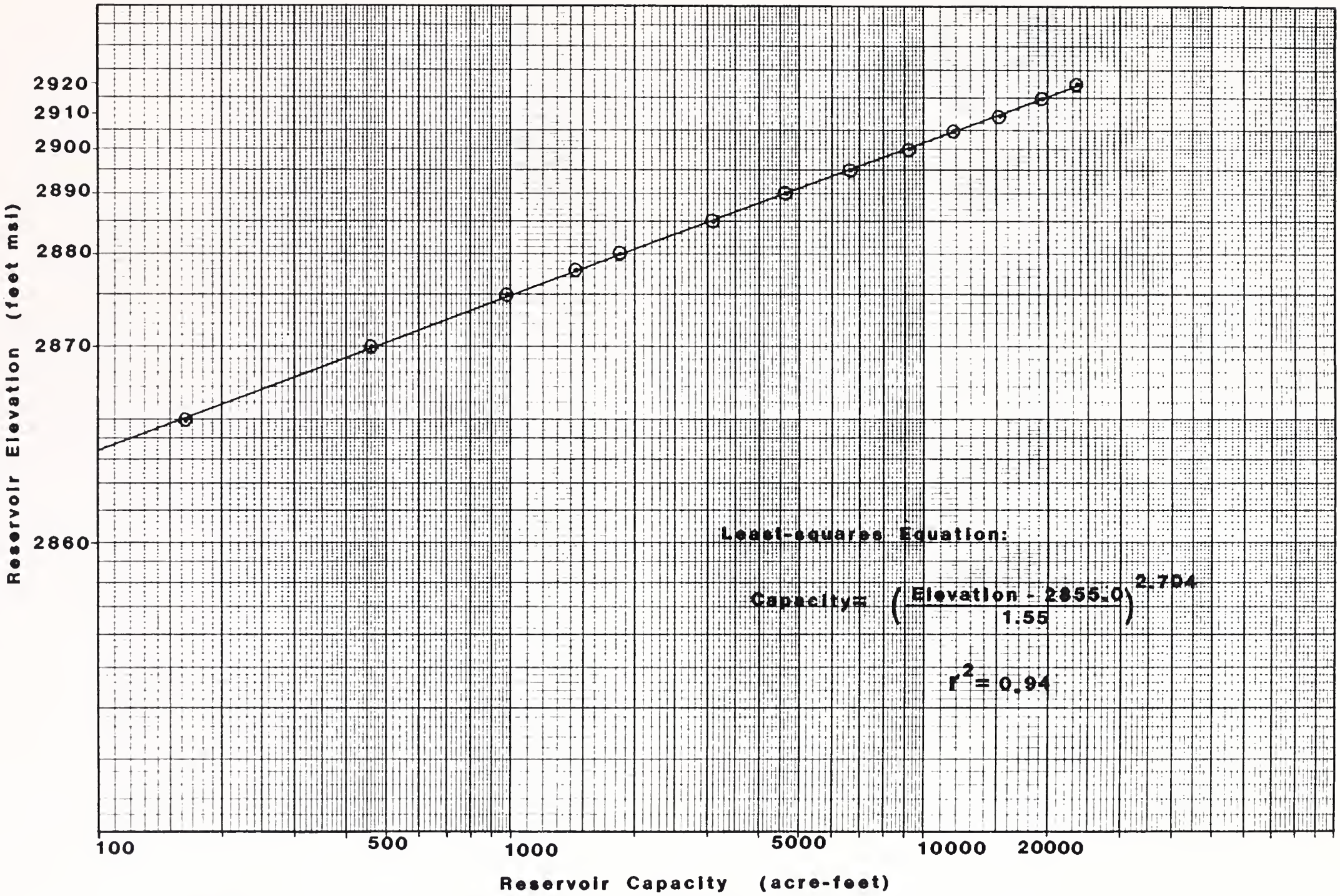


Figure 2—2. Capacity as a Function of Water Elevation, Petrolia Reservoir.

Table 2-3

Comparison of 1945 and 1984 Elevation-Capacity Curves for Petrolia Reservoir

	Based on 1945 map	Based on 1984 map
Elevation (ft)	Capacity (acre-feet)	Capacity (acre-feet)
2900	9800	9120
2898.6	9200	8380
2895	7900	6660
2890	5200	4660
2885	3700	3070
2880	2100	1820
2878	1500	1440
2875	1200	990
2870	400	457
2865	370	162
2860	0	30
2855	0	Negligible
2848	-	0 (outlet elev. 2848)

CHAPTER 3. VOLUME AND WEIGHT OF RESERVOIR SEDIMENT

SEDIMENT SAMPLING AND PROBING

Sediment cores ranging in length from 5.0 to 8.0 feet were taken from ten sites on plate 2 (designated RS-), using a raft-mounted piston-hammer corer. Core segments were sealed tightly after collection, transported to Helena, and analyzed for wet and dry specific weight.

In addition to the piston cores, 2-inch-diameter Shelby cores were taken at ten sites (plate 3), and specific weight determinations done on most. Sediment thicknesses were probed by hand at 27 sites (plate 2) in the exposed portion of the reservoir.

Appendix B gives methods for coring and probing. All core sites and two probe sites were triangulated with alidade. It will be possible to reoccupy these sites in the future.

THICKNESS AND VOLUME OF RESERVOIR SEDIMENT

Based on the sediment coring and probing data, and numerous stratigraphic observations of field exposures and air photo interpretation, a sediment isopach (thickness) map was constructed. Thickness contours of 0, 1, 2, 4, 6, 8, and 10 feet were plotted on the 1984 base map (plate 3). A discussion of the sediment distrubution, lithology, and depositional patterns is presented in Chapter 4. Volume calculations based on plate 3 are accurate to ±20%.

The volume of sediment accumulated in Petrolia was calculated using the average end-area method. Thickness-area and area-volume information are given in table 3-1. Over the 33-year period since impoundment, Petrolia has accumulated 1100 acre-feet of sediment. Of this, 87% (960 acre-feet) is within the thickness interval of 0-4 feet. Only a few places in the reservoir have accumulated thick sediments.

The sediment accumulation (1100 acre-feet) added to the present reservoir capacity at the spillway elevation (8380 acre-feet) results in an original capacity of 9480 acre-feet (±3%). This is comparable to the 1945 value of 9200 acre-feet. Given the generalized nature of the 1945 map, the agreement between capacities is remarkable. Although the 1945 map was adequate for preliminary design work and

Table 3-1

Sediment Volumes and Distribution of Sediment
Accumulated in Petrolia Reservoir

Thickness Interval (ft)	Total area[1)] in Interval (acres)	Cumulative Area (acres)	Av. End Area (acres)	Interval Volume[2] (acre-feet)	Cumulative Volume[2] (acre feet)
0-1	90	425		380	1100[3)]
			380		
1-2	107	335		282	730
			282		
2-4	158	228		298	448
			149		
4-6	38	70		102	149
			51		
6-8	25	32		40	47
			20		
8-10	7	7		7	7
			3.5		
10-12	0	0		0	0
				1100[3)]	acre-feet

[1] areas determined from sediment thickness map (plate 3)

[2] accurate to ±20%

[3] number is rounded

estimation of total capacity, we found it grossly inadequate for site specific determinations of sediment thickness.

Sediment volumes tabulated for the west arm, pool above dam, and south arm (Appendix F) show that twice as much sediment has been deposited in the south arm as in the west arm; west arm = 300 acre-feet, pool = 200 acre-feet, and south arm = 600 acre-feet. The difference in drainage areas above the west arm (212 square miles) and south arm (400 square miles) appears to explain the difference. Yellow Water Reservoir removes about 55 square miles of the west arm drainage area from sediment production, which further explains smaller sediment volume.

SPECIFIC WEIGHT OF RESERVOIR SEDIMENT

The specific weight (defined as the dry weight of sediment in a unit volume -- lb/cu ft.) of sediment accumulated in Petrolia is influenced by lithology and grain size, depositional environment and depth, and time (Vanoni 1977). Analysis of 53 samples taken from 18 sediment cores shows that the silt and clay deposits in the reservoir have specific weights varying from 30 lb/cu ft. to 85 lb/cu ft. Appendix G gives the results of the specific weight measurements.

Specific weights are largely a function of position in the reservoir (depositional environment) and depth of burial. Grain size was not measured but visual description of samples shows that the upper portions of the south and west arm contain a high percentage of silt. These areas which are frequently exposed and subjected to considerable drawdown, have the highest specific weights (65-85 lb/cu ft.). In the pool area, sediment deposits are at an elevation of 2870 ft. and below. Most of this sediment is nearly always submerged and specific weights are lowest (30-65 lb/cu ft.). These results are similar to those reported for other Montana reservoirs (table 3-2).

To extrapolate the measured specific weights to the entire volume of reservoir sediment, the 53 samples were split into three groups identical to those used in volume calculations: west arm, pool area, and south arm. For each area log-log plots of specific weight vs. depth were prepared, giving the following relationships (log-log plots given in Appendix G):

West Arm:	$S = 55\ D^{.26}$	where,
Pool Area:	$S = 29\ D^{.59}$	S = specific weight (lb/ft^3)
South Arm:	$S = 68\ D^{.11}$	D = depth (ft)

(equations based on best-fit lines by eye)

Coefficients of the expressions indicate the relative magnitude of specific weights. Exponents show that specific weight increases most rapidly with depth in the pool area, and least rapidly in the south arm.

Table 3-2

Specific Weights Reported for Other Reservoirs

Reservoir	Specific Weight (lb /ft^3)	Source[4]
Yellow Water Reservoir	32	Estimated by SCS[1], 1948
Fort Peck Reservoir	56 to 60	Measured by CE[2], 1950-60
" " "	13 to 35 (submerged); 71 to 101 (exposed)	Measured by CE[2], 1960-65
Tongue River Reservoir	71	Measured by BR[3], 1948
Petrolia Reservoir	30 to 85	Measured by Streamworks 1984

1 USDA Soil Conservation Service

2 US Army Corps of Engineers

3 USDI Bureau of Reclamation

4 USDA 1975

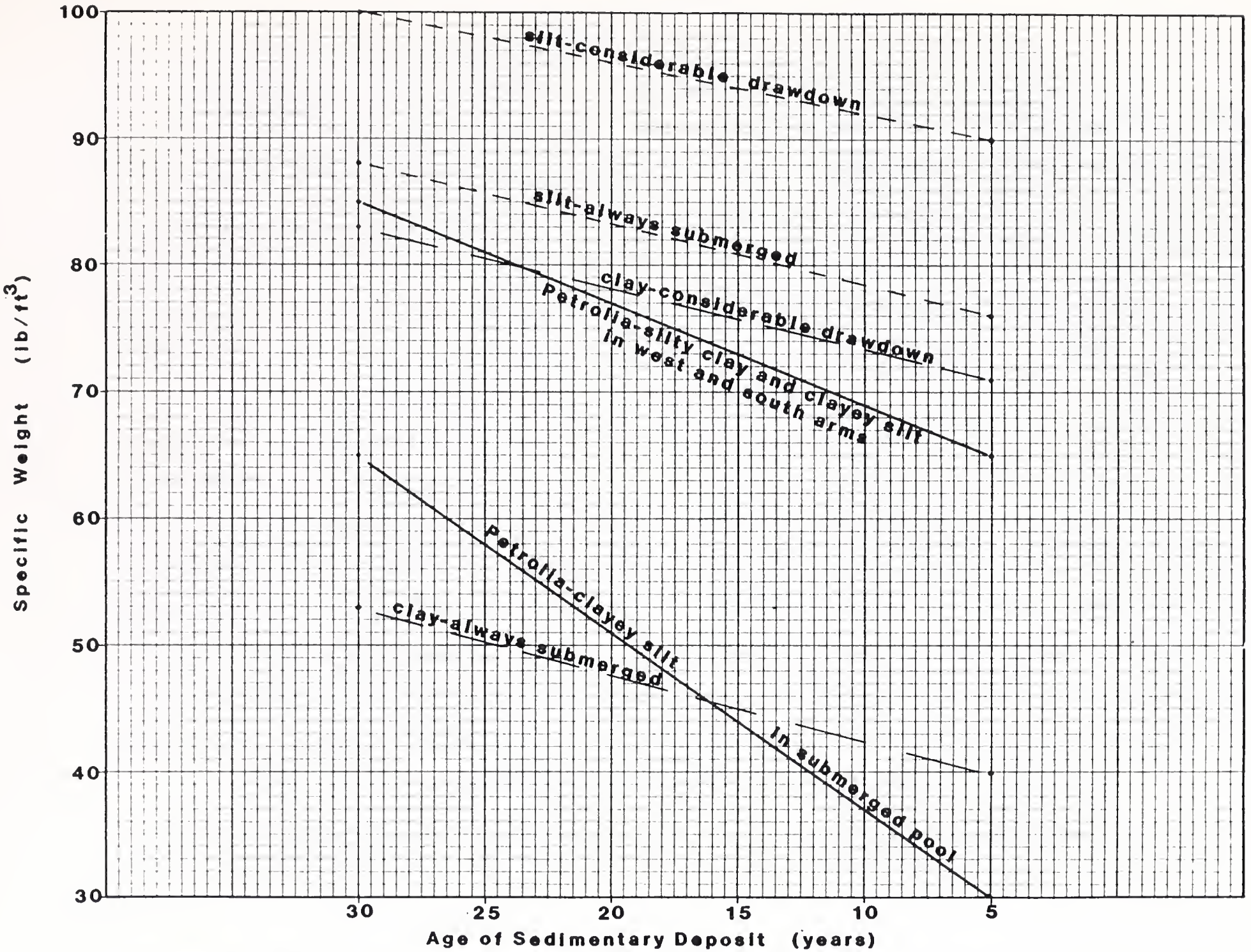


Figure 3—1. Typical Variation in Specific Weight of Reservoir Sediment with Grain Size and Age of Deposit (dashed lines after Lane and Koelzer, 1953: solid lines indicate measured range for Petrolia).

The expected variation in specific weight of fine-grained reservoir sediment is shown in figure 3-1, which is based on Lane and Koelzer (1953). The measured specific weight of Petrolia sediments in the western and southern arms (primarily silty clays and clayey silts which are frequently exposed) is represented by the upper solid line; the lower solid line represents clayey silt sediments in the pool area.

To convert the measured sediment volumes to weight, the volume data in Appendix F (tables F-5, F-6, F-7) was combined with the equations relating specific weight to depth for each arm and the pool area of the reservoir. A total weight of 1.6×10^6 tons (±20%) of sediment has accumulated in Petrolia. Table 3-3 and figure 3-2 summarizes the distribution of sediment by thickness interval for the whole reservoir. About 80% of the sediment, by weight, is in the interval of 0-4 feet thick.

Sediment weights computed by thickness interval for the west arm, south arm, and pool area are given in Appendix G: tables G-2, G-3, G-4. The west arm contains 4.1×10^5 tons of sediment in contrast to the south arm which has 9.9×10^5 tons and the pool area with 1.8×10^5 tons.

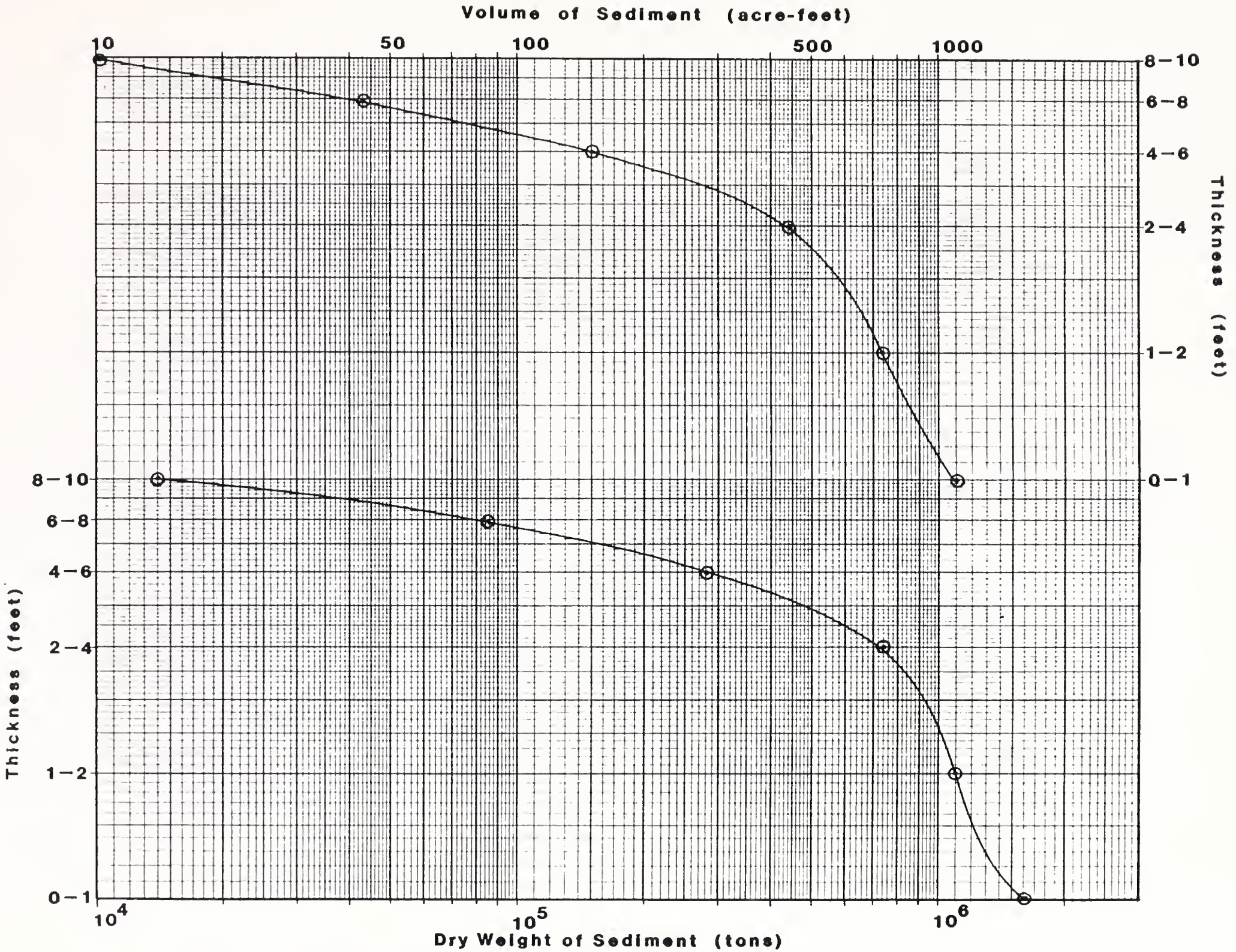


Figure 3–2. Distribution of Sediment Weight and Volume by Thickness Interval, Petrolia Reservoir.

Table 3-3

Cumulative Weight of Sediment
Deposited in Petrolia Reservoir

Thickness Interval (ft)	Total Weight in Interval[1] (tons)[2]	Cumulative Weight[1] (tons)[2]	% of Total Sediment in Interval
0-1	4.5×10^5	1.6×10^6	28%
1-2	3.8×10^5	1.1×10^6	25%
2-4	4.7×10^5	7.5×10^5	29%
4-6	1.9×10^5	2.8×10^5	12%
6-8	7.2×10^4	8.6×10^4	5%
8-10	1.4×10^4	1.4×10^4	1%
10-12	0[3]	0[3]	

1 accurate to ±20%

2 2000 lb

3 plate 1 shows a small amount, about 5×10^3 tons in this interval -- less than 0.3% of the total accumulated weight

CHAPTER 4. DISTRIBUTION OF RESERVOIR SEDIMENTS

SEDIMENT LITHOLOGY

Clay and Silt.

Silt and clay, along with less abundant fine-grained sand, are the predominant sediments in Petrolia Reservoir. Silt, sandy silt, and fine-grained sand thinly mantle shoaling bottoms and form the shallow parts (topset beds) of deltas, while clayey silt fills the deep lower pool and the abandoned channels of the pre-reservoir streams. Admixtures of silt and clay are common.

Samples of wet, soft clayey sediment appear to contain mostly clay, but actually are clayey silt or slightly clayey silt, with typically less than 30% clay. This sediment is medium- to dark-gray in color, because of iron sulfides, reduced hydrous iron oxides, and decaying organic matter. The sediment rapidly oxidizes and turns shades of light grayish yellow when exposed to air.

In contrast, silt and sandy silt typically are colored shades of medium-light gray or light-grayish yellow, and closely resemble silt beds in the underlying stream alluvium.

Clay minerals are, in approximate order of abundance, illite, smectite, and traces of palygorskite and kaolinite. The smectite is an "expandable" clay that exchanges cations and water in and out of the mineral structure. Identification of the clay minerals was done by X-ray diffraction, as described in Appendix D.

Above Petrolia Reservoir, expandable clays are characteristic of the Mesozoic bedrock in the lower and middle part of the Flatwillow Creek and all of the Elk Creek-Yellow Water Creek drainages. The Colorado Shale, in particular, contains much smectite, along with quartz and feldspar silt and fine-grained sand. These areas are the probable source of the smectite in the Petrolia sediments. Most of the clay and silt probably enters the reservoir via its south (Flatwillow Creek) arm, because the drainage area above the south arm is larger.

Illite is the common clay in Paleozoic formations, which underlie the upper third of the Flatwillow Creek drainage. Illite also forms in soils by alteration of other clays, and thus illite is not necessarily diagnostic of a Paleozoic source for the Petrolia Reservoir clays.

The X-ray study and microscopic examination of several cores show that the silt and fine sand is mostly quartz, with considerable feldspar, calcite, chert, and poorly crystalline iron oxides or sulfides as subordinate constituents. These minerals are consistent with source rocks in the drainages above Petrolia Reservoir.

No marker horizons or key beds distinguished by mineralogy were found in the cores. A special search was made for volcanic ash from the Mt. St. Helens eruption. There is no identifiable ash in the uppermost six inches of sediment in three cores (RS-10, RS-11 and HP-1). Appendix D gives details of the ash investigation.

Sand and Gravel

On beaches and bars of the reservoir's south arm are local deposits of gravel, pebbles, and cobbles, and fine- to coarse-grained sand. These relatively coarse-grained sediments are not volumetrically significant, as compared to silt and clay.

The pebbles contain clasts of sandstone derived by local erosion of the Eagle Sandstone along the shores of the reservoir, and a variety of more resistant rocks, including chert, chalcedony, and limestone. These latter rocks are mostly reworked from nearby stream alluvium, which is exposed along several beaches of the reservoir and above the reservoir along the channel beds of Flatwillow and Elk Creeks. Alluvium is also exposed in a few places (mainly in the west arm) on the bottom of the reservoir, at local sites where currents and waves have kept the pre-reservoir surface free of reservoir sediment.

The sand is mostly in an upper delta at the very south end of the south arm of the reservoir, in topset beds. Very little of the sand has been moved into the deeper pool.

Examination of the bars and riffles of the major streams above the reservoir shows that larger floods, such as those in 1975 on Pike Creek (plate 1) and nearby areas, must move gravel, cobbles and coarse-grained sand along the creek beds from one bar to the next. These floods have delivered little of this coarse-grained sediment to the reservoir -- otherwise, the upper delta in the reservoir's south arm, and the upper end of its west arm would have gravel deposits. And, only the south arm is receiving a significant influx of sand. Probably, gravel and pebbles are being stored within tributary drainages -- on the flood plains or in stock ponds along small streams, at bases of hillslopes, and on small alluvial fans. Major storms could move much of this stored sediment out and down to Petrolia Reseroir.

DEPOSITIONAL PATTERNS

Deposition in the South Arm.

The bulk of the sediment in the reservoir occupies the upper south arm, which receives the flow of Flatwillow Creek and its tributaries Pike and Spring Creeks. In the south arm, the pre-reservoir alluvial channel is nearly, and in some areas entirely filled with silt and subordinate clay and sand that form two deltas: an upper, well-developped one, and a lower, poorly-defined one. The sediment distribution map (plate 3) clearly shows the upper delta but not the lower one, whose map pattern is distorted by pre-reservoir topography. The upper delta was deposited by one or several floods when the pool was full, or nearly so, while the lower delta was deposited by a small flood when the pool was deeply drawn down, perhaps during the late summer. Streamflow records in the area are not complete enough to date the floods, but there was a large flood in 1975 in the Flatwillow drainage.

The upper delta has built up from approximately 2892 to 2899 feet, just above the high pool (spillway) level. The upper surface of this delta is colonized by a dense willow thicket. During drawdown in late summer, the bare, silty, gently sloping delta front becomes carpeted by a jungle of cockleburs 1 to 4 feet high, infested with rattlesnakes. Beavers have built dams that locally trap sediment on the upper surface of the delta.

A recent channel (possibly diverted by beaver dams) excavated through the east side of the upper delta provides a cross-sectional view through the delta. Exposures on the side of the channel show an upward-coarsening sequence of delta sediments, where silt and sand beds (top-set beds) have built northward over silt and clay delta-front (fore-set) beds and soft, black, clayey silt beds deposited in the protected quiet water of the south arm before formation of the delta. Appendix C presents a measured section of the uppermost 10.4 feet of delta sediment.

The lower delta in the south arm was deposited between elevations of approximately 2877 and 2882 feet, and remains submerged except during dry years when the reservoir is drawn down deeply. Reservoir sediment is more than 10 feet deep in the upper delta, but only 5 to 7 feet deep in the lower delta.

Aerial photos taken in August of 1984, when the reservoir was at pool elevation of 2878 feet (a fairly low water level) clearly show a system of distributary channels in the south arm, on a low terrace just west of the old channel of Flatwillow Creek. These channels mark the top of the lower delta; the remaining sediment of the delta is in the channel to the east and northeast of the terrace, about half way down the south arm.

There are no obvious deltas in the west (Elk Creek) arm of the reservoir.

In the south arm away from the two deltas, old alluvial terraces, natural levees, and abandoned channels are thinly mantled by reservoir sediments that typically range in thickness from 1 to 3 feet, and locally thicker. The sediment mantle is thick enough in most places to partly or completely obscure the pre-reservoir alluvial topography. The sediment layer is consistently thin on knolls (old natural levees and terrace remnants), thicker in swales and low terrace flats, and thickest in abandoned channels. In abandoned channels, the reservoir sediment reaches 3 to 5 feet in thickness, and is clayey silt. Elsewhere, the sediment mantle consists of sandy silt and slightly clayey silt, from which currents and waves have winnowed most or all clays.

Deposition in the West Arm.

In contrast to the south arm, little sediment mantles the submerged terraces, levees, and abandoned meander loops that flank the winding, incised pre-reservoir channel of Elk Creek. Typically, the sediment layer is ony 0.5 to 2.0 feet thick, except in abandoned channels on the old flood plain, where sediment commonly is 2 to 5 feet deep. There are no deltas in the west arm. And, in most places, the pre-reservoir alluvial morphology is very clearly displayed on aerial photos taken during reseroir drawdown.

As in the south arm, the sediment is thinner on knolls (mostly underlain by pre-reservoir natural levees and terrace remnants), and thicker in swales.

In the upper, or western half, of the west arm the sediment mantle is dominantly silt. Probably, clays are washed (winnowed) out by currents and waves in these areas, which are shoal areas for much of the year. The swales are more protected from winnowing action, and retain a little clay (the deposits are slightly clayey silt), while the deep pre-reservoir alluvial channels are protected from wave and current action and thus receive mostly clayey silt deposition from suspension. These clayey silts are soupy and dark to medium gray in color, and probably rarely dry out completely, even where exposed during late summer drawdown of the reservoir.

Deposition in Deep Pool

In the central, deep pool of the reservoir clayey silt and slightly clayey silt (less than 5% clay) settle out from suspension. Clay and silt grains are suspended and moved from the shore or from bars during storms and windy periods. In mid-reservoir these fine-grained sediments settle out, along with organic detritus, which is mostly twig and leaf fragments. These sediments are

mostly soupy, dark to medium gray in color, and stink, suggesting low oxygen content and little bioturbation.

This sediment thinly mantles the pre-reservoir flood-plain topography. Even low-relief features of the old floodplains of Elk and Flatwillow Creeks are not masked by the thin -- typically 0.5 to 2.5 feet thick -- layer of fine mud. Thus, flood-plain steps one or two feet high, and low natural levees flanking the old channels, are still clearly distinguished on fathometer charts of the deep pool.

When the reservoir is deeply drawn down, as it was late in the summer of 1984, the muddy bottom is partly exposed and begins to dry, oxidize, and change to a lighter color. The clayey silt become mud-cracked, with cracks as deep as two feet. The sediment surface becomes covered with tiny, hard mud chips, which blow with the wind. This process may produce a mud-chip breccia, noted by us in the south arm at site HCS-2 in the uppermost 0.3 feet of reservoir sediment. Also, cracking and brecciation mixes the sediment and partially or completely destroys any original bedding that otherwise might serve as key beds for deciphering the history of sedimentation.

In the deep pool, the old channels, which were originally incised 4 to 6 feet into the flood plains, are now partly or completely filled with silt and clay. Along several traverses low in both arms of the reservoir (along range 3-W in the west arm, and in much of the south arm, for example) the old channel is nearly filled, and is difficult to distinguish on fathometer traces.

Deposition on Beaches and Bars

Around the shore of the reservoir, wave action (and probably ice expansion and bulldozing during the winter) undercuts the shore, forming many sandy and silty beach deposits.

The shoreline is composed mostly of pre-reservoir alluvium. There are also short segments of shore where bedrock (the silty, shaley Telegraph Creek Formation and the Eagle Sandstone) is exposed and eroded by waves. These beach deposits may contain gravel and pebbles.

Silt, fine-grained sand and subordinate clay comprise both the alluvium and bedrock formations and thus the beach sediments closely resemble the sediment brought to the reservoir by the creeks.

A few silt-sand bars are being constructed by wave action. The best example is on an island formed during reservoir drawdown in late summer, in the mid-west arm. There, west winds erode the west shore of the island, wash over the island, depositing silt and sand on the crest as a berm, and depositing fine silt and a little

clay as an overwash fan in quiet water on the east side. During August, 1984 when the water level dropped one to two feet, the west side of the berm began eroding to form a low wave-cut cliff.

Spits are forming off several of the points along the west side of the south arm. They consist of silt, sand, and gravel eroded along the shore and brought to the points by longshore currents. They are not volumetrically significant.

Comparison of aerial photos taken July 6, 1954 and August, 1984, shows that the shoreline has maintained its initial configuration with only small changes. Thus, although steep, high cutbanks at many locations suggest appreciable shoreline retreat, shoreline erosion at most locations has been minor. Lag deposits of gravel, pebbles, and cobbles inhibit shoreline retreat along the east and north shore.

CHAPTER 5. TRAP EFFICIENCY AND SEDIMENT YIELD

The trap efficiency of Petrolia Reservoir is the percent of the total incoming sediment retained by the reservoir. Trap efficiency is usually expressed as a ratio of the amount of sediment deposited to the total sediment inflow (Borland 1971). It depends upon the geometry and capacity of the reservoir, amount of inflow, sediment size, and reservoir operation.

Two empirical methods were used to estimate Petrolia's trap efficiency. Brune (1953) related trap efficiency to the capacity and average inflow of reservoirs. Using this method resulted in a range of trap efficiency from 90 to 98%. A second method, developed by Churchill (1948) which relates trap efficiency to retention time and mean water velocity, gave a trap efficiency of 99%.

These values are probably high for Petrolia. The empirical curves may not account for local processes which influence sediment discharge from the reservoir. These include operation of a bottom outlet which has apparently been self-maintaining. Observations suggest that the reservoir may be very efficient at discharging soupy clay deposits in the lower pool area (Taylor 1984). Also we observed that the arms of the reservoir are subjected to wind driven wave erosion of shallow submerged terraces - this increases the turbidity of the water and suspended sediment discharge from the reservoir. Without direct measurement of sediment inflow and outflow from Petrolia, it is not possible to precisely evaluate the effect of sediment sluicing or wind suspension on the reservoir's trap efficiency. A reduction in trap efficiency of 10 to 20% seems possible.

Estimation of mean annual sediment yield from the Petrolia data has two principal sources of error. First, the sediment weights are accurate to ±20%; second, the trap efficiency may range from 70 to 98%. If the errors compound (i.e. low trap efficiency and over estimate sediment volume, or conversely, high trap efficiency and under estimate sediment volume), the possible maximum range of error in sediment yield ±34%. Therefore, we report the sediment yield as 85 tons/square mile/year ±34%.[1]

By equally dividing the pool area sediment accumulation and summing the halves with both reservoir arms, the yield of sediment to the west and south arms was estimated. Sediment yield to the West Arm is 87 tons/square mile/year ±34% (assuming 80% trap efficiency of Yellow Water Reservoir); yield to the South Arm is slightly lower, 83 tons/square mile/year ±34%.

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1 this yield assumes an 80% trap efficiency for Yellow Water Reservoir and an effective sediment contributing area of 568 square miles.

CHAPTER 6. LAND USE AND EROSION IN THE PETROLIA DRAINAGE

INTRODUCTION

Plate 4 shows land use in the Petrolia drainage. Land use is strongly controlled by precipitation and by the availability of water for irrigation, while problem erosion is strongly controlled by bedrock and grazing intensity. Locally, wind, soil fertility and infiltration capacity, saline soils, or steep slopes limit agriculture and increase soil erosion. Old burns, and grazing by wildlife in pre-settlement times also affect the present pattern of land use, but little is known about these.

Land recently plowed and put to dryland crops (sod-busted land) has not yet eroded noticeably, but has the potential to do so during intense rains or spring meltoff.

General Patterns of Erosion in the Petrolia Area.

Plate 5 is a map of erosion problems and saline soils in the drainage basin above Petrolia Reservoir. Areas mapped as having observed erosion problems include areas of bare or nearly bare soil, and areas with many gullies or seepage steps. These eroding areas follow strong trends that are mainly a function of the slope of the land and the parent material of the soil. Locally, land use also increases erosion rates, particularly where poor conservation practices coincide with slopes over about 8% on erodible soils. Most of the problem areas are in the east half of the basin, in areas underlain by the Colorado and Claggett Shales.

Most areas with erosion problems in the Petrolia basin are hillslopes in areas with shale, claystone, or siltstone bedrock. Typically, the eroding slopes fall from hogbacks that are held up by resistant sandstone or limestone beds. Less commonly, rapidly eroding slopes lie on terrace margins. There is little obvious evidence of erosion problems on slopes less than approximately 8%. A major exception is erosion in areas of saline soil, which typically are in bottomlands and on toes of slopes; these slopes are commonly less than 8%.

Table 6-1 qualitatively summarizes the overall erodibility of soft, relatively erodible bedrock formations of the Petrolia area. Most of these formations are shaley (clayey) or silty. As general rule, soils developed on these formations are erodible where exposed to raindrop impact -- as would happen on bare fields or heavily

grazed range. The generalizations in the table agree well with mapped patterns of accelerated erosion in the study area (plate 5).

The main streams and their principal tributaries are not downcutting their channels; rather they are stable or aggrading slightly. There are shallow discontinuous gulley systems in the smallest (first and second order) drainages, but they are not extensive. Seepage steps are locally present on hillslopes; these and gullies are mapped on plate 5.

Precipitation and Temperature.

Precipitation roughly follows elevation in the Petrolia drainage. High, forested areas such as the headwaters of Flatwillow Creek in the Big Snowy Mountains have an annual precipitation of over 20 inches, while the dry hills near the reservoir have 12 to 16 inches. Appendix E contains tables of temperature and precipitation measurements for Grassrange, just north of the Petrolia watershed.

Appendix E also contains a map of the "rainfall factor," or "R factor" for the Petrolia drainage. This factor is used in calculating quantitative estimates of soil erosion from cropland, using the Universal Soil Loss Equation (Wischmeier and Smith 1965, 1978). The rainfall factor values quantitatively reflect the erosional potential of raindrop impact and the potential for turbulent surface runoff to move dislodged soil particles from a cropped field. Rainfall factor values range from 25 in the dry hills south of the reservoir, to 31 at the reservoir, 34 near the confluence of the North and South Forks of Flatwillow Creek, and slightly above 80 at the headwaters of these forks in the Big Snowy Mountains. High values indicate the potential for rapid soil erosion, other factors being equal. The map was compiled by the U.S. Soil Conservation Service (SCS), and was obtained from the SCS Lewistown office.

Soil Maps.

The SCS is currently mapping the soils of Petroleum county in detail, and this information will be of great use in future studies in the Petrolia drainage, particularly where sod busting has been extensive (plate 6).

The modern, detailed SCS soils map for Fergus County provides useful information, but this is not the prime area of concern for the Petrolia study, nor is there widespread accelerated erosion (plate 5) or sodbusting (plate 6) in the Fergus County portion of the Petrolia drainage. The map is not yet published, but a preliminary version is on file in the SCS Lewistown office.

The SCS has tabulated "K," or "erosion factor" values for the soil units mapped in Fergus County. The upper half, roughly, of the Petrolia area is in Furgus County. K values are derived from quantitative measurements of erosion within small, artifically bared

plots of land of known slope and slope length, and are designed for use in predicting soil erosion rates on cropland, not rangeland (Wischmeier and Smith 1965, 1978). However, we would expect these values to be high where erosion problems are observed in the area (plate 5), in areas where the sod and shrub cover has been partially or completely destroyed -- but they are not. (The SCS has mapped a "Tomty soil" in the foothills of the Big Snowy Range, in the upper Petrolia drainage. The Tomty soil does have a high K value -- see table 6-1.) Perhaps in the Petrolia area historical and present land use (such as heavy grazing) on range may be more important controls on erosion rates than soil erosion factors.

The following sections describe the major land uses in the Petrolia drainage, along with observed patterns of erosion problems (areas of accelerated erosion). An attempt is made to distinguish between man-caused and natural erosion, but this is not reliably done for many parts of the area because of the lack of information about the land-use history and soils.

RANGELAND

Rangeland is extensive in the semiarid central and eastern parts of the Petrolia drainage. Much of this rangeland is underlain by the Colorado Shale, and has impermeable soils of low fertility, with local salinity problems. Some of the present rangeland was formerly cropped, then abandoned (plate 4). Sites subject to high winds along ridges and high benches are commonly rangeland, although nearby areas protected from winds may be forested or cropped.

Jorgensen (1979) mapped habitat types of range vegetation in the Yellow Water Triangle, which is the area south of State Highway 20 between U.S. Highway 87 and State Highway 244. He describes each habitat type qualitatively, making generalized observations about soil associations, susceptibility to soil erosion if grazed or cropped, and past erosional and land-use history. His study covers about half of the Petrolia drainage, and will serve future erosion studies in that vicinity with an excellent starting point. Vegetation plot measurements and large-scale habitat-type maps were compiled by him, and were left on file with the Montana Department of Fish, Wildlife, and Parks at its Lewistown office.

In the central and eastern parts of the Petrolia drainage, many of the slopes mapped as rangeland on plate 4 in actuality do not have a full sod and shrub groundcover. Rather, there is either bare soil, or soil with less than an estimated 50% vegetative groundcover, or bedrock outcrop. We do not know if all or part of this relatively bare ground had a more continuous sod and shrub cover in the past, or not. At present, this land provides at best a marginal range for cattle or sheep. Probably, high grazing pressure in the past, possibly coupled with repeated range fires, has led to a reduction of the vegetative cover and to much of the present accelerated erosion mapped on plate 5. Study of old photos, along with interviews of landowners, might resolve this question.

Geomorphically, most of these nearly bare areas are active pediments -- gently sloping erosion surfaces forming by the action of sheetwash during rainstorms. Pediments are common in Montana, but most are inactive and sod-covered, with modern streams and gullies incised into their surfaces. This is not the case with many of the Petrolia pediments, particularly in the Yellow Water drainage.

In contrast, sod-covered terraces (which are extensive in the Petrolia area) are in general erosionally stable surfaces of very low relief. Although locally gullied or subject to rilling and erosion by overland flow during heavy rainfalls, there is little field evidence for widespread, rapid erosion of concern. This is in part because some terraces are shallowly underlain by very permeable sand and gravel beds, so that overland flow is not often obtained during rains or spring melt. Other terraces are capped with fertile wind-deposited silt (loess) or flood-plain silt and fine sand. These terraces generally support a dense sod cover even where heavily grazed, and soils there do not erode easily. Geologically, the terraces have been erosionally stable since their formation; the oldest (highest) are about 2 to 3 million years old, while the very youngest are post-glacial, that is, younger than about 10,000 years.

Terrace margins, in contrast, are locally gullied or rilled, and are vulnerable to land-use abuse such as heavy grazing.

Soils on terraces and terrace margins are more subject to accelerated erosion where they are cropped without irrigation. This is discussed further in the following section.

IRRIGATED LAND

Irrigated land (plate 4) is almost entirely restricted to floodplains and low terraces along creeks. Irrigated land extends west up tributaries of Flatwillow Creek to the west part of R. 21 E., and into the headwaters tributaries of Elk Creek.

There is little irrigated land along the bottomlands of Yellow Water and Pike Creeks because these creeks have little water, and because their lower and middle sections have extensive saline soils that are unsuitable for crops. The saline soils are derived mostly from the Colorado Shale. Presumably, Elk and Flatwillow Creeks have enough flow to flush out most of the salts from bottomland soils, while Yellow Water and Pike Creeks do not. Areas underlain by the Claggett Shale, south of Flatwillow Creek and the escarpment of the Eagle Sandstone are also locally very saline; some of this land is irrigated in low-lying areas.

Little irrigated land has been abandoned. Salt buildup in soils along Yellow Water Creek may have led to abandonment. Abandoned bottomland in the foothills of the Big Snowy Mountains (along tributaries of Flatwillow Creek) may be where small homestead ranches were abandoned. The same may have happened along the headwaters tributaries of Elk Creek.

NON-IRRIGATED CROPLAND

The following description of dry croplands does not include recently sod-busted land, which is treated in a separate section.

Dry Cropland on Foothill Benches of the Big Snowy Mountains

Non-irrigated crops replace range and sparse forest on high, benches that slope gently down to the east at about 1 to 3 degrees, in the western third of the Petrolia drainage. These benches are formed on the erosionally-stripped surfaces (dip-slopes) of slightly tilted resistant limestone beds of the Alaska Bench Formation. Alaska and Middle Benches, for example, have large fields; approximately one-third of these fields are abandoned. Those remaining are cropped with grains. Wind erosion of soil is locally a problem, but there is little field evidence for water erosion.

Dry Cropland on Terraces

Lower in the Petrolia drainage, non-irrigated cropland (mostly planted to winter wheat and barley) covers broad terraces that flank the valley bottoms and locally occupy the interfluves between major streams. These terraces are remnants of glacial and younger pediments and strath terraces. Wind erosion of soil is common in fields on the terraces, but there is only local evidence (rilling, small discontinuous gullies) of water erosion.

Many of the grain-fields are abandoned. Abandonment is particularly common where saline soils are developed on terraces underlain by the Colorado Shale.

Dry Cropland on Uplands

Locally, there are wheat and barley fields on the broad, rounded hillcrests and backslopes of low hogbacks held up by resistant sandstone beds. This is characteristic of areas underlain by the upper part of the Eagle Sandstone, the Kootenai Formation, sandstones in lowermost Colorado Shale, and sandstones in the Ellis Formation. These areas typically have sandy and loamy soils, better drained than soils developed on the Colorado Shale. Because of the good infiltration capacity of the soils, overland runoff is rarely obtained during rains, and the soils are relatively immune to serious erosion. Also, many of these upland areas have more precipitation. Hence, the soils produce good crops and there are few abandoned fields (plate 3). Wind erosion is locally a serious problem, particularly along the tops of the broad hillcrests and in saddles.

Dry Cropland on Alluvial Fans

Small alluvial fans lie at the mouths of many gulches that open onto the relatively wide floodplains of the main creeks. They are particularly common along the northern side of Flatwillow Creek's floodplain. The fans slope gently (rarely over about 10 degrees), and contain silt, clay and gravel. Locally, the range grasses and shrubs on the fans are plowed under, and the small fields are planted to dry land grains. Aerial photos show that some of these fields were irrigated in the past, but few are irrigated today.

There are few erosion problems on the alluvial fans, other than minor rilling and discontinuous, shallow gulleying.

SOD-BUSTED RANGE

Rangeland plowed and put to non-irrigated crops is shown on plate 6 (but not on plate 4). An extensive but discontinuous area of recently broken range lies southeast of Flatwillow Creek in T. 12 N., R. 26 and 27 E.. There, the new fields have soils developed on the upper Eagle Sandstone and lowermost Claggett Shale. Many of the soils derived from the Eagle are sandy and relatively permeable, and therefore resistant to water erosion. In contrast, on the Claggett there are clayey and silty, relatively impermeable soils that have the potential for serious erosion problems.

A large block of recently broken range lies north of Elk Creek, between state highway 244 and Petrolia Reservoir. There, broken ground lies on a series of terraces (erosional remnants of pediments and strath terraces) that lie directly on the upper Colorado Shale and Telegraph Creek Formation. On terrace margins and along the sides and bottoms of shallow valleys, soils are locally shallow, relatively impermeable, and thus highly erodible. Soils on the nearly horizontal terrace surfaces are more resistant to erosion, but not totally so.

Most of the newly-broken range is planted to winter wheat. Most first and second order drainages are broken to cropland, with no buffer of sod or shrubs left to slow overland flow where gullying or rilling would form.

Some of the sod-busted fields were previously broken to dry cropland, then abandoned to range. The abandonment may date to dust-bowl days, but we have not interviewed local ranchers or agency specialists about the land-use history of the area. This could be done for individual drainages if intensive sediment budget and erosion rate studies are undertaken, as described in Chapter 7.

FORESTLAND

Extensive commercial and non-commercial forestlands are mostly in the western half of the basin, where precipitation is higher than in the semi-arid regions to the east. There is little timber in the lower drainage where the bedrock is the Colorado Shale, Telegraph Creek Formation or Claggett Shale. Low soil fertility and high soil salinity, and perhaps range fires, may contribute to the absence of forests.

High winds desiccate and kill young trees on ridges and high benches or terraces. This process probably limits forest development along the hogbacks and high benches in R. 22, 23, and 24 E. where there are patches of trees only in sheltered areas. Areas exposed to winds lack forest cover, and locally have oval blowouts (deflation basins). Similar features are developed along the hogback held up by the resistant Eagle Sandstone southeast of Flatwillow Creek in R. 26 and 27 E., and along the high terrace (pediment) remnant south of Flatwillow Creek in R. 24 and 25 E.

Many timbered slopes and hillcrests are too isolated, or have too sparse or slow a growth of trees, to be logged profitably.

In the timbered areas that are marginally or fully commercial, the mapped pattern of logging corresponds more to land ownership than to availability of harvestable timber. On private timberlands, some landowners have harvested their parcels, others not. On public timberlands, much of the timber at low elevation, near the established road network, has been harvested; timber in rugged, high country (in the Big Snowy Mountains proper, for example) has not been harvested.

TABLE 6-1

Bedrock Formations and Soils in the Petrolia Area that are Susceptible to Water Erosion and Mass Movements.

Relative Erodibility	Formation or Soil
	Mass Movement
Low to high	Quaternary terraces
Low to high	Quaternary alluvium
High	Landslides (Quaternary). Developed on Cambrian shale and limestone near Greathouse Peak
	Erodible Bedrock
Very High	Kibbey Formation. Soft claystone, siltstone, and calcareous sandstone
High	Otter and Heath Formations of Big Snowy Group (Mississippian). Shale, siltstone, sandstone, and limestone. Forms strike-valley along Red Ridge Road in T12N, R20E.
High	Tyler Formation of Amsden Group (Pennsylvanian). Claystone; calcareous sandstone, siltstone, and claystone. Local landslides. Along with Big Snowy Group, forms strike valley along Red Ridge Road in T12N, R20E., and on slopes below cliff- and ridge-forming Alaska Bench Limestone.
High	Morrison Formation (Jurassic). Claystone, siltstone, fine-grained limestone. Poorly exposed in slopes and valley bottoms below cliff- and ridge-forming Kootenai and Ellis sandstones and limestones.
Very High	Tomty Soil. Locally developed on Big Snowy Formation in Fergus County. K = 0.37-0.43; K is the soil-erodibility factor in the universal soil loss equation of Wischmeier and Smith (1965).

High	Telegraph Creek Formation. Sandy shale and soft sandstone on steep face of escarpment below resistant Eagle Sandstone.
High to very high	Colorado Shale. Undifferentiated. Sandstone members generally have relatively permeable soils with less surface runoff and less erosion than shaley or silty members. Develops saline soils. Many slopes bare of soil.
Very high	Claggett Shale. Lies above Eagle Sandstone, forms strike valley and slopes leading up to escarpment on southeast. Severe gulleying, seepage steps, minor slumps, major salinity problems in lower part.

CHAPTER 7. CONCLUSIONS AND RECOMMENDATIONS

SEDIMENT YIELD TO PETROLIA RESERVOIR

Over the 33 years since construction, Petrolia Reservoir has lost storage at an average rate of 33 acre-feet/year, ±20%. Mean annual sediment yield for the drainage above Petrolia is within the range 56 to 114 tons/square mile/year. Values measured for other semiarid lands with similar drainages compare favorably. The U.S. Geological Survey measured suspended sediment discharge (1974-79) for similar eastern Montana drainages and found a range in mean annual yields from 1 to 647 tons/square mile/year. Most of the drainages smaller than 2000 square miles had yields less than 70 tons/square mile/year and were commonly less than 10 tons/square mile/year. These yields are based on short periods of record and thus are not strictly comparable with the longer 33-year average yield for Petrolia. However, they are similar in magnitude.

McPherson (1975) reported mean annual yields for prairie drainages in southern Alberta ranging from 50 to 250 tons/square mile/year. Langbein and Schumm (1958) developed a relationship between mean annual precipitation and sediment yield. Using their relation results in a predicted yield of 450 to 650 tons/square mile/year for the Petrolia drainage. Although their study was based on extensive reservoir sedimentation measurements, it represents a period before widespread aggradation began in the Rocky Mountains. Aggradation began in about 1950 (Andrews 1978).

The two deltas in the south arm of the reservoir suggest that the very large floods, such as those in 1975 on Pike Creek (plate 1) and nearby areas, are important in moving large quantities of clay, silt, and sand to the south arm. In the 15-year or longer periods between major floods, little sediment, other than clay and small amounts of silt, moves down the streams and into the reservoir. Presumably, soil is eroded from slopes, then deposited and stored temporarily within tributary drainages -- on flood plains, in stock ponds along small streams, at bases of hillslopes, and on small alluvial fans. Major storms can move much of this stored sediment out and down to Petrolia Reservoir: this has happened twice in the drainage above the south arm, but not at all above the west arm.

Streams above both arms have delivered little coarse sediment -- gravel and pebbles -- to the reservoir, and yet there are abundant deposits of these sediments on channel bottoms of Flatwillow and Elk Creeks. This suggests that much coarse-grained sediment is stored on the channel bottoms of these trunk streams. In the

future, floods larger than those during the reservoir's past history will surely move large quantities of gravel and pebbles to the reservoir.

In summary, deposition in the reservoir probably involves both yearly increments of clay and silt delivered by ordinary runoff events -- say, 1- to 20-year floods -- and large slugs of sediment brought in by major floods. To date, the latter has delivered silt and some clay and sand to the south arm. Much of the soil eroded on slopes is probably stored temporarily in tributary drainages.

LAND USE AND EROSION: CONCLUSIONS

There is potential for significant future increases in the rate of sediment delivery to the reservoir if grazing pressure is increased in the drainage, or if large areas of range are sod busted. Plate 5 shows large areas where the vegetative ground cover is lacking, probably in part because of past grazing and dryland cropping. There are also large remaining areas with good to marginal range that are highly susceptible to erosion if misused (Jorgensen 1979).

The principal and obvious land-use practice that leads to erosion problems in the Petrolia area is heavy grazing. The great extent of very shallow soils and bare shaley or silty bedrock suggests that in the past, soil loss in these areas has been consistently high, higher than the replacement weathering rate (or deposition rate, for wind-deposited soil) for the lost soil. In the lower and middle part of the Petrolia drainage, we suspect that much of the abandonment of cropland and the loss of range sod cover was caused as much by buildup of salts in the soil and water erosion of fertile topsoil as by drought and wind erosion in the dust-bowl thirties. This is substantiated by our field observations of much saline soil, very shallow soils, and bare shale and siltstone bedrock in many of the abandoned parcels.

There are few areas where it is obvious that poor cropping practices have caused serious loss of soils. This does not, however, mean that this has not or will not happen. Our reconnaissance inventory of the Petrolia drainage did not include periods of heavy rains or rapid snow melt, when soil erosion might be observed. And rills and shallow gullies are commonly plowed over and destroyed. That is, the evidence for long-term soil loss may be lost. Studies of other areas with similar soils suggests that severe erosion commonly results from dry-cropping steep slopes, cropping on slopes without using contour plowing or terracing, and plowing out minor draws and swales without leaving a buffer of sod and shrubs.

We conclude that there is potential for serious soil erosion in heavily-grazed rangeland, and in sod-busted (plowed-out range) land, during big storms and very rapid spring melt-offs. This conclusion, however, is qualitative, and not well-substantiated by other than reconnaissance-level field studies.

RECOMMENDATIONS

We propose a number of studies to measure and describe erosion in sod-busted and range areas. The past history of soil loss, buildup of salts in soil, and the detailed relationship of these processes to landuse could thus be partially deciphered. And, the studies would quantify the present-day rates of erosion as related to land use.

The proposed studies include the following:

-- follow-up work on Phase I studies of sediment buildup in Petrolia Reservoir;

-- a sediment survey of Yellow Water Reservoir, less elaborate than the Phase I survey of Petrolia Reservoir;

-- a detailed study of long-term sediment yields from eight small watersheds, using stockponds, to relate the effects of land use on sediment yield; emphasis will be placed on a comparison of sod-busted land versus rangeland;

-- a second detailed study to measure the sediment budget of two very small watersheds, one in range, the other cropped with wheat;

-- direct measurements of runoff and sediment discharge in major streams -- a contingency item, depending on weather;

-- a preliminary plan for long-term monitoring of sediment yield; this is the follow-up for the five studies listed above.

These studies are described in more detail below. Each could be done independently of the others, but in total they comprise an integrated approach to understanding sediment yield in the Petrolia drainage. (A more detailed proposal has been submitted to the Department.)

Follow-up Work: Time Horizon in Petrolia and Yellow Water Reservoirs.

Scattered layers of carborundum grinding compound on the bottoms of Petrolia and Yellow Water Reservoirs will mark the present depositional surfaces, and provide a "time-line" that can easily be identified in cores or box samples that might be taken in later years. Sediment in the coming years will cover the carborundum layer, allowing exact calculation of the yearly mean rate of deposition at the marked sites.

Sediment Survey of Yellow Water Reservoir.

A sediment survey of Yellow Water Reservoir will allow comparison of sedimentation rates in the two reservoirs, and also provide information on the relative importance of various sediment sources in the Petrolia drainage as a whole. The Yellow Water survey would be done in 1985, following essentially the same procedures as was done in the 1984 sediment survey of Petrolia Reservoir.

Effects of Sod Busting on Sediment Yield: Paired Watershed Studies.

A quantitative study of sediment yield versus erosion rates allows the effects of the principal variables that control sediment yield to be measured and evaluated. We propose a paired watershed study of sediment yield involving four pairs of watersheds. In each pair, a rangeland watershed acts as a control drainage, and a cropped (recently sod-busted) watershed acts as an experimental drainage. The drainages will have areas of one to three square miles, and have similar watershed characteristics. In each drainage, a 15-plus year historical, or baseline, sediment yield will be measured by means of a sediment-probe and sampling study of an existing stock pond at the mouth of the drainage.

The proposal includes screening of potential drainages and selecting the paired watersheds for study; inventorying and quantifying those drainage basin characteristics (soils, bedrock, slope, aspect, precipitation, vegetation) which control sediment yield; and conducting stock-pond sediment surveys to measure baseline sediment yields.

Effects of Sod Busting on Sediment Yield: Sediment-budget Studies.

The paired-watershed study described in the preceeding section has a significant limitation. Sediment yield is an accurate measure of overall erosion in a drainage basin only if the total annual amount of eroded sediment is exported from the drainage. However, research suggests that much sediment is redeposited -- "stored" -- in a drainage soon after it is eroded, and that sediment movement through semi-arid drainage basins is a discontinous process influenced strongly by climatic variation.

Therefore, we propose to directly evaluate erosion and sediment storage in addition to total sediment yield, for several drainage basins. At least two small sub-drainages (one sod busted, one a control) will be instrumented for detailed measurement of sediment production and storage, as well as total sediment yield. These measurements would form the basis of a quantitative sediment budget (Leopold et al. 1966).

By choosing similar, small (approximately 0.2 square miles) drainages representative of sub-basins within the larger (1 to 3 square miles) paired watersheds, the detailed information given by sediment-budget studies may be extrapolated to the overall set of paired watersheds described in the preceeding study.

The proposal for sediment-budget studies includes: site selection; analysis of basin characteristics that control sediment yield; installation of devices to measure erosion and deposition; and initial baseline measurement. A plan for future surveys to monitor sediment erosion, storage, and yield in the sub-drainages is also given.

The study includes detailed ground-surface surveys, erosion pin techniques, and sediment traps to quantify erosion and storage in the two drainages. At the outlet of each a sediment trap will be installed to measure the total sediment yield from the drainage.

Direct Measurements of Runoff and Sediment Discharge in the Sediment-budget Drainages.

Direct monitoring of annual sediment yield through daily measurement of streamflow and suspended-sediment concentrations is very expensive. We propose a modification of this approach, to provide comparative information on sediment runoff during major sediment-producing storms. Simultaneous (synoptic) measurement of storm runoff will allow construction of sediment hydrographs for several points in each watershed, and increase the usefulness of the other sediment erosion, storage, and yield measurements.

Direct measurements during runoff events provides more immediate, site-specific results than do sediment-trap surveys. However, direct measurements can be difficult to make, given the unpredictability of weather. Therefore, in the course of our 1985 and future field work, we will be equipped for synoptic monitoring on a contingency basis.

Long-term Monitoring, Measurements, and Report.

Long-term monitoring and measurements is needed after installation of equipment, surveying, and baseline studies are done in 1985. The frequency of measurements depends largely on climate. If the present trend towards drought continues, only two resurveys of sediment monitoring instrumentation may be sufficient over a ten year period. If the climate becomes wetter, annual or biennial monitoring might be warranted.

The long-term monitoring plan accounts for this uncertainty by providing a limited annual monitoring program to determine whether a complete resurvey is required. In addition, examination of on-site precipitation records every two months (from March through October) will give a clear indication of the need for monitoring.

Stock-pond resurveys will measure the long-term or "post-treatment" sediment yields from the paired watersheds. We suggest that the ponds be resurveyed approximately every two to three years, for a total of ten or more years. Resurveys are also desirable after each major runoff event. Resurveys of the erosion pins, traps, and ponds should be repeated annually or biennially, following summer runoff, or less often when field inspection shows negligible erosion or sediment yield. Additional surveys are also desirable after each major runoff event.

An annual report to the Department will summarize all monitoring results. Five to ten years of monitoring will allow assessment of sediment erosion, storage, and yield. A final report would contain an analysis of the effects of sod busting on sediment yield.

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APPENDIX A.

METHODS USED IN MAPPING LAND USE AND EROSION

METHODS USED IN MAPPING LAND USE

Plates 4 and 5 show existing land use in the study area. Land use information is from three sources: U.S. Agricultural Stabilization and Conservation Service (ASCS) aerial photos; Fergus and Petrolia County land-use maps (scale 1/2 inch = 1 mile) published by the (former) Montana Department of Community Affairs; and limited field mapping. Field mapping was done by driving county roads and viewing the land through binoculars. This proved somewhat unsatisfactory because the low topographic relief made it difficult to see field and forest boundaries.

The maps are reconnaissance in level, and have not received a systematic check by land owners and agency personnel.

Cropland.

Irrigated land, non-irrigated cropland, and abandoned cropland were mapped by interpreting large-scale (6 inches = 1 mile) 1975 orthophoto maps of active cropland; these photos are on file at the ASCS in Lewistown, Montana. The ASCS has updated the orthophotos to show most changes in active cropland between 1975 and 1982. Through photo-interpretation and reconnaissance field work we identified additional irrigated and non-irrigated fields that are not shown on the ASCS photo maps, as well as numerous abandoned fields.

There is land newly broken to cropland during the past two years in the lower part of the drainage, east of state highway 244. Plate 4 shows this newly-broken, or 'sod-busted' land. The plate was compiled from a series of large-scale (8 inches = 1 mile) aerial-photo maps made in 1983 by the ASCS Lewistown office. Land sod busted since 1983 is not shown. Plate 5 overlays plates 1 and 4, to provide an integrated picture of the drainage and land-use patterns.

On the orthophotos, the boundaries of some abandoned fields were difficult to distinguish from rangeland. The main criterion used in mapping abandoned cropland was the presence of lineations, either in one direction or crosshatched, within polygonal areas that were slightly lighter or darker than adjacent areas. We suspect

that such patterns may also form by seeding rangeland, by using draglines to remove sage or other vegetation, and from cutting grass several times on rangeland. In cases of doubt, the areas were mapped as rangeland, but probably a few rangeland areas were mistakenly mapped as abandoned cropland. Nonetheless, plate 4 shows the general distribution and extent of abandoned cropland.

Areas classified as irrigated land include all types of irrigated land -- roller, center-pivot, and flood. Also included are sub-irrigated hayfields and pasture, that lie on the active flood plain, or on flood-plain steps and the lowest terraces. Cropland on higher terraces is not sub-irrigated, and is mapped as non-irrigated cropland. Also included in the non-irrigated classifcation are dry croplands on slopes and hill crests.

Forestland.

Plate 4 presents two categories of forestland: commercial and non-commercial. These were mapped by transferring the map units for 'commercial forest' and 'forest cover areas', respectively, from the Montana Department of Community Affairs 1977 maps of Existing Land Use Fergus County, and Existing Land Use Petrolia County. A limited number of these maps remain available from the U.S. Soil Conservation Service, Bozeman. Forest cover areas (on non-commercial forest land) are defined on the Department of Community Affairs maps as:

> "Coniferous and deciduous tree areas displaying a natural tree canopy or crown cover of 15% or more. This category includes forested areas unsuitable for commercial harvest or those that fall within management areas that preclude harvest."

And commercial forest areas are defined as:

> "Areas managed for timber harvest. Clear-cut areas and those in various stages of managed growth are included. Tree stands actively being harvested and those that may be harvested are mapped. The timber management activities in these areas include road-building, thinning, slash disposal, tree planting, timber cutting, and cull tree removal. Commercial forest areas on public land and private lands managed by major commercial forest products industries are shown."

In the Petrolia drainage, there are a number of forested, logged areas that are privately owned, but not by major forest-products industries. Also, there are a number of timber groves not mapped by the Department of Community Affairs. We added these areas to our land-use map by photo-interpreting U.S. Geological Survey orthophoto quadrangle maps (scale 1:24,000). These orthophotos were taken in 1975 in the Petroleum and eastern Fergus Counties, and in 1977 in the upper drainage (the Big Snowy Mountains). We made no attempt to measure the precise percentage of canopy cover, nor to include tiny, isolated patches of timber.

No doubt there are many privately-owned timber stands mapped on plate 4 as non-commercial forest that will be logged in the next several decades. Also, some forestland interpreted as non-commercial was probably logged many years ago, but is not identifiable using the photos available to us during this reconnaissance mapping.

Rangeland.

Rangeland was mapped from orthophotos just as described above for cropland. The difficulties in distinguishing rangeland from abandoned cropland are described above, under cropland.

In the high peaks of the eastern Big Snowy Range are extensive alpine and subalpine meadows, along with steep talus and avalanche slopes. This open ground is included with rangeland on the land-use map (plate 4).

Jorgensen (1979) notes in his study of plant habitat types that range and forest fires have ravaged the Petrolia drainage in the past, and that there is no record of the number and extent of these fires. The former extent of forest versus upland grassed areas now used as rangeland is thus unknown, but could well have been considerably altered from the present distribution.

METHODS USED IN MAPPING EROSION

Plate 5 shows accelerated erosion and saline soils in the drainage basin above Petrolia Reservoir.

To prepare plate 5, we defined and mapped areas of "accelerated" erosion as those areas with greater than approximately 50% bare ground so that bare soil or bedrock is extensively exposed. Also included in this mapping category are areas with evidence for severe sheetwash erosion or rill erosion. Most areas mapped as having accelerated erosion also include some subareas with few erosion proablems. In the text of this report, we use the phrase "erosion problem area" synonymously with "area of accelerated erosion."

The map also shows areas where rilling or gulleying is particularly abundant. However, individual gullies and rilled slopes are not mapped.

No distinction was made between man-caused and natural erosion, because the Petrolia drainage has been subjected to a little-studied but long history of land-use and climatic changes, range fires, and grazing by cattle, buffalo, and deer. We made no quantitative measurements of of the percentage of ground cover; rather, we mapped areas of low ground cover using rough, eye-ball estimates. Areas with obvious white crusts of salts on the soil were mapped as saline soils.

The map was compiled from reconnaissance field observations, and photo-interpretation of 7 1/2 minute U.S. Geological Survey orthophoto quadrangle maps of the Petrolia drainage. The map is definitely reconnaissance in level, in that it was difficult to photo-interpret areas of low or absent ground cover accurately for all different bedrock types. Red shale and siltstone bedrock did not show up on the orthophotos as clearly as did light- to medium-gray colored shale and siltstone, and both could be confused with relatively non-erodible sandstone outcrops. Saline soils were distinguished relatively consistently except for several orthophotos in the vicinity of Yellow Water Reservoir, where photo contrast was very low. Further field checking would improve the accuracy of plate 5, but the plate does show general patterns of erosion problems and saline soils for the present reconnaissance study of sediment yield.

Table 6-1 summarizes the overall erodibility of various soft, bedrock formations of the Petrolia area. The table was compiled from reconnaissance field observations and information in geology reports for the area (Johnson and Smith 1964; Reeves 1927, 1931; Zimmerman 1956; Gardner 1950; and Smith 1962). Most of the formations are shaley (clayey) or silty. As a general rule, soils developed on these formations are erodible where exposed to raindrop impact--as would happen on bare fields or heavily grazed range. The table presents qualitative generalizations, not quantitative ones, and there are many exceptions to the conclusions, because erosion does not depend merely on bedrock properties and the impact energy of raindrops. Nonetheless, the generalizations in the table agree well with mapped patterns of accelerated erosion in the study area (plate 5).

APPENDIX B

SURVEYING, SOUNDING, AND CORING TECHNIQUES USED ON PETROLIA RESERVOIR

SURVEYING

Horizontal and vertical control was established in the spring and summer of 1984. The survey established two baselines, one along the reservoir's north side, one along its east side, each starting at point 0+00 at the north end of the dam. From each baseline, the survey extended sediment ranges (transects) across the reservoir. Topography was surveyed along several of the transects in the upper portions of the reservoir arms, and a topographic map constructed for the upper south arm.

The 34 sediment ranges are spaced at approximately 500- to 1000-foot intervals. Standard survey procedures with a six-second theodolite and EDM were used to locate all reference points. Principal monuments were established by driving 3-foot sections of 1/2 inch rebar into the ground, leaving 0.1 feet above the surface (a brass cap on re-bar was placed at station 0+00) and marking with an aluminum cap die-punched with the range number. Detailed survey notes are on file with the Department of Natural Resources.

All monuments are located 50 to several hundred feet from the present high-water shoreline of the reservoir. Additional secondary reference points were placed near the shoreline, to give more convenient survey control for soundings and sediment sampling.

SOUNDING

Profiles of the reservoir's bottom were made in July 1984 along the sediment ranges, using a Raytheon DE-719C acoustic depth finder. The bottom profiles were used to draw a topographic map of the sediment surface below 2878 feet (plate 2) and to construct a new area-capacity curve (figure 3-1) for the reservoir.

The fathometer was mounted on a 14-foot shallow-draft outboard motor boat. Profiling of the reservoir bottom involved traversing along pre-surveyed range lines, with cross-bearings taken from shore at up to seven places along each traverse.

The fathometer charts give a permanent record of the reservoir's bottom. The cross bearings, and bearings taken on the beginning and end points of each traverse were used to calculate the true distance and horizontal scale of each traverse segment. This was necessary to correct for changes in boat speed as wind conditions changed during each traverse. Water depths are generally accurate to plus or minus 0.5 feet, but the relative relief of the bottom is typically shown to 0.1 to 0.3 feet, depending on wave and wind conditions. The boat was kept within +/- 5 feet of the line of traverse on about 75% of the traverses; on the remaining traverses winds blew the boat as much as 15 feet off-line. The fathometer charts and tables of reduced horizontal distances and water depths are on file with Streamworks and the Department.

Using the fathometer charts of the reservoir bottom, a topographic map (plate 2) was compiled with a five-foot contour interval for the reservoir pool below an elevation of 2878 feet. The new area-capacity curve was based on this map, plus a photogrametrically compiled map from Associated Surveys Inc. (Billings) for the elevation range 2878 to 2900 feet. Associated's map is based on photos taken in August 1984, and has a five-foot contour interval. We added supplementary contours where needed in areas of low relief, including parts of Associated's map up to 2890.0 feet, the water level at the time of the fathometer survey.

Chart Speed.

One inch per minute condenses the record too much at a slow boat speed. There is not enough room for writing notes on the charts and there is too long a delay before fix marks. Otherwise this speed provides adequate record. (One inch per minute does suffice to record depths adequately.)

Two inches per minute is ideal for this project. Four inches per minute wastes paper. The bottom topography in Petrolia Reservoir is fairly subdued, so that fast chart speed is not needed.

Caution: Remember to reset chart speed to two inches per minute after using the four inches per minute rate to advance the paper to get space for notations, as is often done before beginning a traverse.

Checklist for Notations on Chart.

Before a traverse note:

--Direction of travel (that is, "from 4-W south toward 204");
--Speed of chart (1, 2, or 4 inches per minute);
--Wind intensity and direction and constancy;
--Date (on first traverse of day; optionally on others;

--Distance from shore (if known; see below for measuring technique), or description of bouy or pole marker;
--"start" with arrow pointing to fix mark at beginning point;
--Approximate start time (during start there is usually not enough time to note exact time) (optional);
--Number of segments to be marked (optional); and
--Check of calibration.

During a traverse note:

--Wind changes and trends;
--Fix marks, numbered consecutively, with arrow to each mark;
--Bottom features as pertinent;
--Notations and fix marks as needed to note any bouys, poles or other reference points passed along the traverse, course changes, errors (accidental fix marks, false starts,...); and
--Checks and adjustments on chart (e.g. "Cal. Zero check").

At the end of a traverse note:

-"end", with arrow to fix mark;
--Notations describing any bouys or poles placed to mark end;
--Approximate or measured distance to shore along the line of the traverse;
-Approximate time the traverse ended (so that water elevation interpolation may be done if needed; 1984 Petrolia traverses were of short duration, so that there was no real need for noting the time at the beginning and end of each traverse); and
-check of calibration.

Starting Traverses

Measuring distance from shore at start of traverse Tie a 25 foot, light-weight (about 1/4 inch) poly rope to boat at or near the transducer, and attach a weight, such as a water bottle (full of water or sand). Toss the weight onto the shore beside or shoreward of lath, pole, or cairn marking the line of traverse at the water's edge. Evade barking dogs and talkative fisherman. Start the boat along the traverse, and make the first fix mark on the chart just as the weight enters the water. The transducer is exactly 25 feet from the shore at this fix.

It is difficult to toss the rope and weight and operate the motor and boat at the same time, so we had the depth-recorder operator move to the back of the boat and toss the weight, freeing up the

pilot. The operator then rapidly moves forward to the depth recorder and fixes the mark as the weight enters the water. This takes some practice if the wind and waves are strong. In calm conditions, the weight may be placed on shore, the boat positioned by hand or by rowing; the motor is then started, the traverse speed reached, and the traverse begun.

Approach In wavy, windy conditions, you must approach the traverse start by heading upwind along the shore, or looping upwind into the start, maintaining speed as the traverse begins. Otherwise, waves and wind will throw the boat onto the shore or past the traverse line. In whitecap, or near-whitecap conditions, the traverse cannot generally be started or done with a 14 foot boat and 15 horsepower motor, without speeds too high for taking cross-bearings from shore during the traverse.

Bouys and range poles These may optionally be used to mark the beginning and or end of a traverse, especially where the bottom shoals into less than two or three feet of soft mud along the shore, so that the boat cannot approach the shore. Also, a range pole may be placed by hand into the bottom, opposite the transducer, just as the boat abruptly slows as it encounters the bottom at the end of the traverse. The pole-to-shore distance is then taped, or cross-bearings taken on the pole and shore by the instrument operator, who then calculates the distance to the shore. Use of bouys or range poles is less efficient than use of a rope and weight to measure the distance from shore to a traverse start.

If the traverse ends without placement of a pole and measurement (as might happen in high winds or waves), then the distance to the shore is estimated by eye, and recorded on the chart.

Calibration of Raytheon Depth Recorder

Frequency At the beginning and end of each day, and at noon, weather permitting, calibrate the depth recorder.

Accuracy and precision With waves over about one foot high, it is not possible to calibrate better than plus or minus 0.3 feet. In calm water or with a breeze to about five mph, you can calibrate to approximately plus or minus 0.1 to 0.15 feet. A sidewise tilt of the boat can lift or drop the transducer by as much as six inches during a traverse. We adjusted anchors and gear to keep the boat as level as possible, but typically a plus or minus 0.2 to 0.3-foot error is expected, even in calm water.

To plumb the depth of the bottom and to calibrate, we taped a measuring tape to a poly 1/4 inch line, and tied a two-foot-wide horizontal iron plate to the line. The plate was lowered to 25 feet, then succesively raised to 20, 10 and 5 feet; repeating as

needed until calibration was obtained by adjusting the Tide and Depth knob so that the chart stylus recorded the true depth to the plate. The plate gives a well-defined chart reading. Calibration can be accidentally changed during the traverse (or at any time) by bumping Cal. Zero, Speed of Sound, or Tide and Draft knobs. The zero calibration was checked routinely during each traverse, except during several of the first traverses, when techniques were being worked out. This check was noted on the chart, whether or not the adjustment was needed, for most traverses.

Fix Marks

Fix marks were either calculated in advance or set by timing minute intervals during the traverse.

Bearings were taken at each end of the traverse, or at the shore(s) near the ends of the traverse if the end or start was not pre-determined with range poles; then the total distance of the traverse was calculated and divided into roughly even segments, whose bearings were then calculated. Segments were generally 250-300 feet long, and the time of traverse for each was typically one to two minutes (less time in calm or light wind, more in strong wind).

The traverse was then begun. The on-shore alidade was set successively on each segment bearing and for each bearing, the instrument operator radioed to the fathometer operator the time that the boat (or rather, a vertical pole at the transducer on the boat) crossed each bearing line. The fathometer operator made a fix mark on the chart at each bearing.

SEDIMENT SAMPLING AND PROBING

Ten sediment cores ranging in length from 5.0 to 8.0 feet were taken in bottom sediments, using a piston-hammer corer designed by John Sales specifically for sediment surveys in shallow lakes and reservoirs. Core sites are marked on plate 2. The corer was operated from a frame suspended from a 14-foot-high tower mounted on a 12-foot by 16-foot raft. The raft had a net working bouyancy of approximately 4500 pounds, loaded with equipment and workers.

The corer uses liners of 2-inch PVC 160 psi irrigation pipe to collect the sediment. The internal diameter of a liner is 2.15 inches, not the nominal value of 2 inches. An eight foot length of the core liner gives a sample volume of 0.20 cubic feet. The sediment-filled core liners were cut into two-foot lengths, and their ends sealed with wax, wrapped in heavy plastic, and taped to prevent escape of water. The core segments were extruded in Helena and analyzed for wet and dry specific weight by Foundation Materials Consultants Inc. (Helena). The sediment cores were described in a

written log with sediment layering, grain size, and color described. The core segments are stored with Streamworks.

In addition to the piston cores, two-inch diameter cores were taken at ten sites with Shelby tubes driven in with a sledge hammer. Plate 2 shows site locations. Specific weight determinations were also done on most of these samples.

Sediment thicknesses were probed by hand at 27 sites in the exposed portion of the reservoir using a ten-foot long wooden rod with a one-inch by one-inch cross section. Plate 3 was compiled from these sediment thicknesses, along with thicknesses from cores. Plate 3 is interpretive in that where measured thicknesses were not available, the thickness was inferred from pre-reservoir topography and known patterns of deposition in the reservoir. This allowed detailed mapping of sediment thicknesses in the west arm, where the sediment mantle over pre-reservoir features is thin, but in the thicker sediment mantle of the south arm this level of detail was not possible.

Triangulation allowed precise mapping of all the piston and Shelby tube core sites, and two of the hand probe sites. It will be possible to reoccupy these sites again at anytime.

The length of each core was measured before and after extraction from the reservoir bottom, and again after extraction from the coring tool, and the percentage of sediment recovery calculated for each. Typical recovery was 70 to 90% of the total depth penetrated by the coring tool.

APPENDIX C.

STRATIGRAPHIC SECTION OF UPPER DELTA IN SOUTH ARM, PETROLIA RESERVOIR.

At sites HCS-6 and ST-1 (located on plate 6) the upper delta in the south arm of the reservoir contains a sequence of sand, silt, and clayey silt beds just over 10 feet thick. In this sequence the grain size increases upward from clayey silt to silty sand. The sequence represents a northward progradation of the delta into the south arm of the reservoir. From the ground surface downward are the following sediment units:

-- 2.5 feet of crudely laminated silt and siltly sand, covered with dense willow thicket; buried soils, iron oxides, root molds: represents topset beds of the delta;

-- 0.75 feet of silt and fine-grained sand, thinly laminated and ripple-marked; laminae of fine plant debris: represents foreset beds of delta;

-- 1.0 feet of laminated fine-grained sand and silt, interbedded with non-laminated slightly clayey silt: represents interfingering of foreset beds with clayey bottomset beds deposited from suspension;

-- 6.2 feet of medium- to dark-gray clayey silt, bedding indistinct: represents bottomset beds -- quiet-water deposition in the south end of south arm before the delta built out over the site;

-- Gravel of pre-reservoir alluvium of Flatwillow Creek.

APPENDIX D. IDENTIFICATION OF CLAY AND SILT MINERALS

X-RAY ANALYSIS OF CLAY MINERALS

X-Min Company, Billings, made a qualitative x-ray diffractometer identification of clay and silt minerals in two sediment samples from site RS-10. One sample was from the uppermost 0.1 ft of sediment, directly on the reservoir bottom; the other was taken from core RS-10 at a level of 2.0 feet below the reservoir bottom. Both samples consist of very soupy, wet, slightly clayey silt, medium-dark-gray in color. The dark color probably comes from poorly crystallized iron sulfides, and perhaps decaying organic matter.

Mounts of the whole sediment were scanned in an X-ray diffractometer. Samples were glycolized and the scans repeated. Copies of the resulting scan records are on file with Streamworks. Quartz was the dominant mineral in both samples; also present were calcite, feldspar (potassium feldspar), clay minerals (including illite and much less abundant smectite, and probably kaolinite and palygorskite). The samples also contained abundant poorly crystallized iron oxides and iron sulfides. In spite of the clayey appearance of samples of the wet sediment, both samples contained less than 30% clay.

The analysis was qualitative. Diffraction peak intensities are highly sensitive to clay-grain orientation, and no standard samples were run to quantify the analysis. Only generalized conclusions about the relative abundances of the several clay minerals may be drawn.

EXAMINATION OF SILT FOR MT. HELENS VOLCANIC ASH

A microscopic examination of silt from three cores was made to investigate the possiblity that a layer of ash from the Mt. St. Helens eruption might be preserved in reservoir sediments. No ash was found.

RS-10 and 11 are cores from the deep central pool of the reservoir, and contain dark-gray, clayey silt and slightly clayey sandy silt, respectively. HP-1 is from the center of a terrace just south of HCS-3 in the south arm of Petrolia Reservoir. It contains medium-light-gray-yellow, slightly clayey sandy silt.

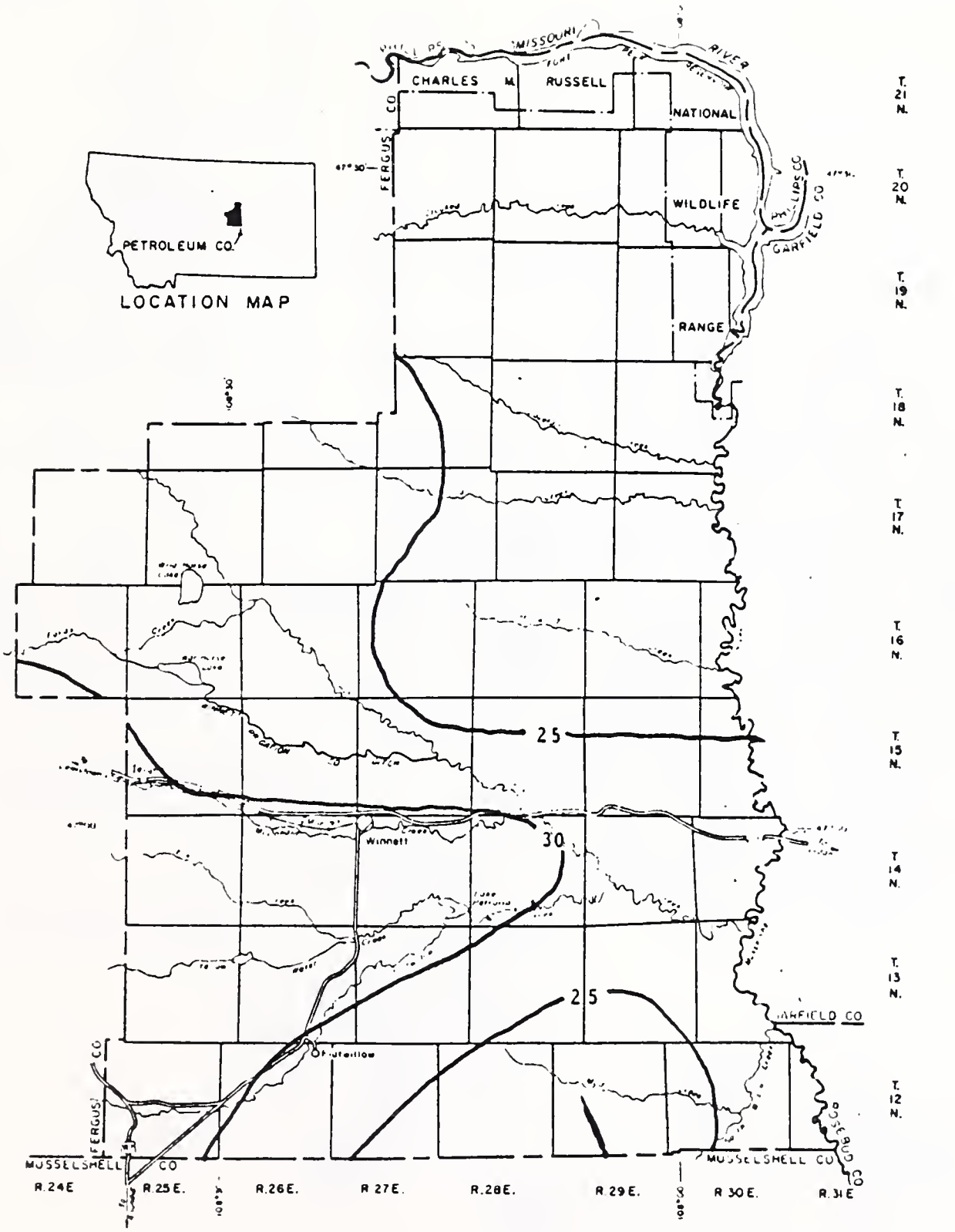
Ash collected in Helena by Ray H. Breuninger just after the eruption contains mostly silt-sized amorphous glass shards, with approximately five per cent sand-sized feldspar grains. Silt and sand sized grains from Petrolia are mostly quartz with subordinate chert. The ash at Petrolia would be finer grained that at Helena. If mixed with and diluted by fine quartz and chert in the reservoir, it could not be distinguished microscopically.

APPENDIX E

TEMPERATURE AND RAINFALL OF PETROLIA DRAINAGE

U. S. DEPARTMENT OF AGRICULTURE

SOIL CONSERVATION SERVICE



RAINFALL AND RUNOFF
FACTOR R FOR

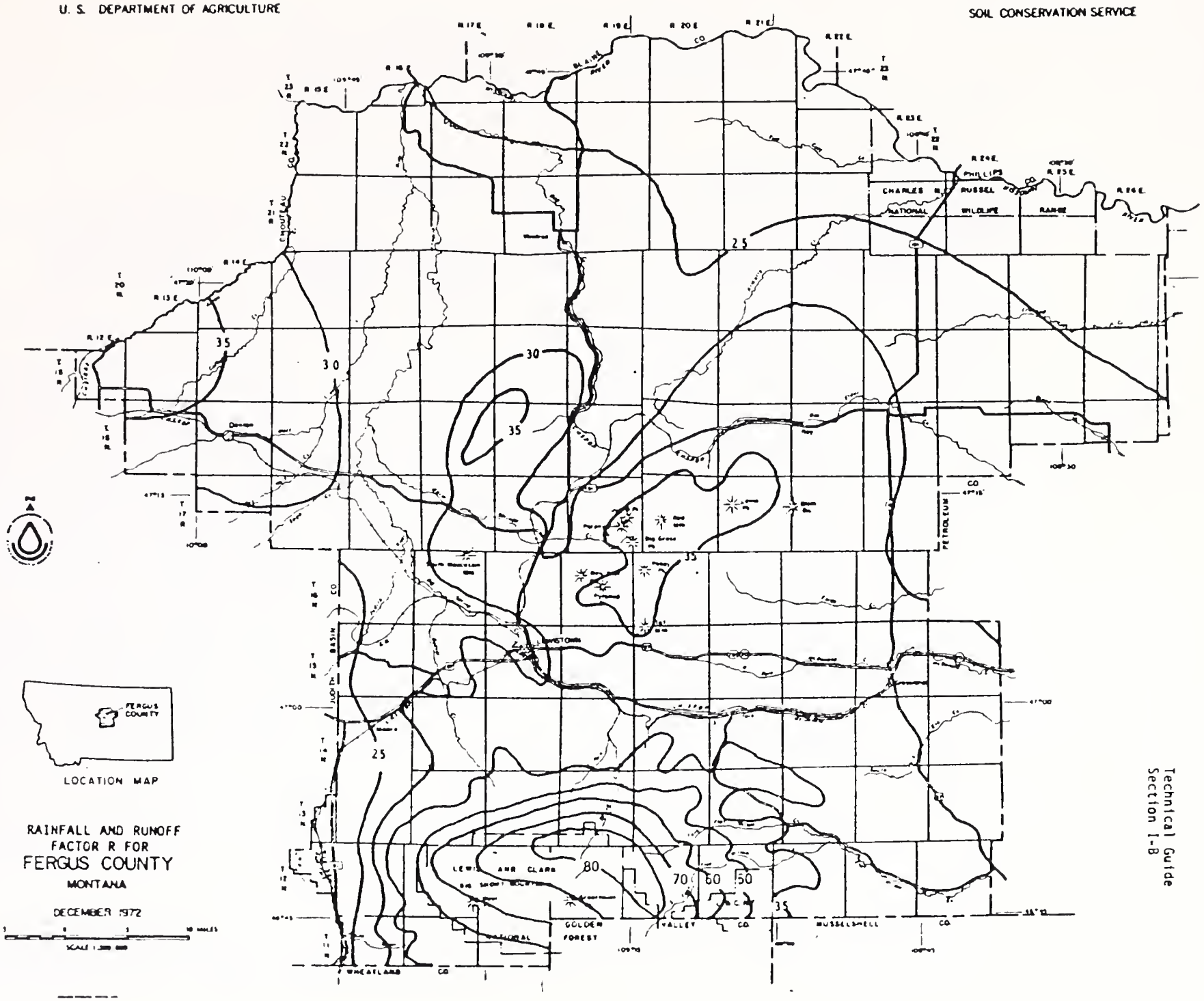
PETROLEUM COUNTY

MONTANA

DECEMBER 1972

U. S. DEPARTMENT OF AGRICULTURE

SOIL CONSERVATION SERVICE



RAINFALL AND RUNOFF FACTOR R FOR
FERGUS COUNTY
MONTANA

DECEMBER 1972

TABLE .--TEMPERATURE AND PRECIPITATION DATA

(DATA WERE RECORDED IN THE PERIOD 1951-77 AT GRASSRANGE, MONT.)

MONTH	TEMPERATURE						PRECIPITATION				
	AVERAGE DAILY MAXIMUM	AVERAGE DAILY MINIMUM	AVERAGE	2 YEARS IN 10 WILL HAVE-- MAXIMUM TEMPERATURE HIGHER THAN--	2 YEARS IN 10 WILL HAVE-- MINIMUM TEMPERATURE LOWER THAN--	AVERAGE NUMBER OF GROWING DEGREE DAYS1	AVERAGE	2 YEARS IN 10 WILL HAVE-- LESS THAN--	2 YEARS IN 10 WILL HAVE-- MORE THAN--	AVERAGE NUMBER OF DAYS WITH 0.10 INCH OR MORE	AVERAGE SNOWFALL
	F	F	F	F	F	UNITS	IN	IN	IN		IN
JANUARY----	33.8	7.0	20.4	62	-32	37	0.78	.27	1.19	3	13.6
FEBRUARY---	41.1	14.0	27.6	68	-21	45	0.44	.12	.69	2	8.9
MARCH------	45.2	17.8	31.6	73	-21	82	0.73	.32	1.06	2	10.3
APRIL------	56.6	27.8	42.2	82	7	139	1.63	.87	2.24	5	10.5
MAY--------	67.2	37.8	52.5	90	21	388	3.12	1.46	4.46	7	1.8
JUNE-------	76.0	45.2	60.7	95	31	621	3.24	1.69	4.53	7	.2
JULY-------	85.7	50.4	68.1	101	37	871	1.53	.68	2.21	5	.0
AUGUST-----	84.5	48.6	66.6	101	35	825	1.57	.56	2.38	4	.0
SEPTEMBER--	73.0	39.7	56.4	94	21	498	1.36	.36	2.15	4	.3
OCTOBER----	63.7	31.3	47.6	88	8	254	0.89	.22	1.42	3	3.5
NOVEMBER---	47.6	20.1	33.8	73	-12	54	0.62	.16	.97	2	8.2
DECEMBER---	39.5	12.7	26.2	66	-27	44	0.54	.10	.87	2	8.3
YEARLY:											
AVERAGE--	59.5	29.4	44.5	---	---	---	---	---	---	---	---
EXTREME--	---	---	---	102	-36	---	---	---	---	---	---
TOTAL----	---	---	---	---	---	3,838	16.45	13.10	19.59	46	65.6

1A GROWING DEGREE DAY IS A UNIT OF HEAT AVAILABLE FOR PLANT GROWTH. IT CAN BE CALCULATED BY ADDING THE MAXIMUM AND MINIMUM DAILY TEMPERATURES, DIVIDING THE SUM BY 2, AND SUBTRACTING THE TEMPERATURE BELOW WHICH GROWTH IS MINIMAL FOR THE PRINCIPAL CROPS IN THE AREA (40 F).

APPENDIX F

AREA-VOLUME AND SEDIMENT VOLUME INFORMATION FOR PETROLIA RESERVOIR

Table F-1

Petrolia Reservoir Area Designations used in Volumetric Calculations

Location* (transect boundaries)	Area	
above 16W-16WB to 2900 contour	1	
16W-16WB to 14W-14WB	2	
14W-14WB to 13W-13WB	3	
13W-13WB to 11W-11WB	4	West Arm
11W-11WB to 9W-9WB	5	
9W-9WB to 8W-8WB	6	
8W-8WB to 6W-6WB	7	
6W-6WB to 3W-204	8	
3W-204 to 2S-204	9	Pool
2S-204 to 6S-6SB	10	
6S-6SB to 7SA-7SC	11	
7SC-7SA to 7SA-8SC	12	South Arm
7SA-8SC to 8S-8SA	13	
8SA-8S to Upstream 2900 Contour	14	

* shown on plate 2

Table F-2

1984 Area-Capacity --- West Arm (Areas 1-8)
Petrolia Reservoir

Elevation Interval (ft Msl)	Total Area in Interval (acres)	Cumulative Area (acres)	Average End-Area (acres)	Elevation Interval Capacity (acre-ft)	Total Capacity (acre-ft)
2900-2895	43.5	261.0		1200	4080
			240		
2895-2890	42.5	218.0		980	2880
			196		
2890-2885	34.7	175.0		790	1900
			158		
2885-2880	30.8	140.0		625	1110
			125		
2880-2878	44.7	109.0		174	484
			87		
2878-2875	20.3	64.3		162	310
			54		
2875-2870	37.1	44.0		130	148
			26		
2870-2865	6.9	6.9		18	18
			3.5		
2865-2860	0.0	0.0		0.0	0.0

Table F-3

1984 Area-Capacity --- Pool Above Dam (Area 9), Petrolia Reservoir

Elevation Interval (ft MSl)	Total Area in Interval (acres)	Cumulative Area (acres)	Average End-Area (acres)	Elevation Interval Capacity (acre-ft)	Total Capacity (acre-ft)
2900-2895	3.9	85.4		415	2560
			83.0		
2895-2890	5.0	81.5		395	2145
			79.0		
2890-2885	3.6	76.5		375	1750
			75.0		
2885-2880	2.7	72.9		360	1375
			72.0		
2880-2878	4.6	70.2		136	1015
			68.0		
2878-2875	4.2	65.6		192	879
			64.0		
2875-2870	4.1	61.4		297	687
			59.4		
2870-1865	20.1	57.3		235	390
			47.0		
2865-2860	25.3	37.2		125	155
			25.0		
2860-2855	11.9	11.9		30	30
			6.0		
2855-2850	0.0	0.0		0.0	0.0

Table F-4

1984 Area-Capacity --- South Arm (Areas 10-14)
Petrolia Reservoir

Elevation Interval (ft. Msl)	Total Area in Interval (acres)	Cumulative Area (acres)	Average End-Area (acres)	Elevation Interval Capacity (acre-ft)	Total Capacity (acre-ft)
2900-2895	41.0	189.0		845	2500
			169.0		
2895-2890	43.0	148.0		635	1660
			127.0		
2890-2885	38.0	105.0		430	1020
			86.0		
2885-2880	28.0	67.0		265	590
			53.0		
2880-2878	2.6	39.0		76	330
			38.0		
2878-2875	7.2	36.0		96	250
			32.0		
2875-2870	16.0	28.7		105	156
			21.0		
2870-2865	9.0	12.7		41	51
			8.2		
2865-2860	3.7	3.7		10	10
			1.9		
2860-2855	0.0	0.0		0.0	0.0

Table F-5

Sediment Volume in West Arm of
Petrolia Reservoir

Thickness Interval (ft)	Total area in Interval (acres)	Cumulative Area (acres)	Av. End Area (acres)	Interval Volume [1] (acre-feet)
0-1	66	186		153
			153	
1-2	64	120		88
			88	
2-4	51	55		60
			30	
4-6	3.6	4		4.4
			2.2	
6-8	0.4	0.4		0.4
			.2	
8-10	0	0		0
				306 acre-feet

[1] accuracy ±20%

Table F-6

Sediment Volume in Pool of
Petrolia Reservoir

Thickness Interval (ft)	Total area in Interval (acres)	Cumulative Area (acres)	Av. End Area (acres)	Interval Volume [1] (acre-feet)
0-1	9	84		80
			80	
1-2	16	75		67
			67	
2-4	59	59		60
			30	
4-6	0	0		0
				207 acre-feet

[1] accuracy ±20%

Table F-7

Sediment Volume in South Arm
of Petrolia Reservoir

Thickness Interval (ft)	Total area in Interval (acres)	Cumulative Area (acres)	Av. End Area (acres)	Interval Volume [1] (acre-feet)
0-1	15	158		151
			151	
1-2	28	143		130
			130	
2-4	48	115		182
			91	
4-6	35	67		100
			50	
6-8	25	32		40
			20	
8-10	7	7		7
			3.5	
10-12	0	0		0
				612 acre-feet

[1] accuracy ± 20%

APPENDIX G

SPECIFIC WEIGHTS OF PETROLIA RESERVOIR SEDIMENTS

Table G-1

Specific Weights of Petrolia Reservoir Sediment Core Samples

Hand-cored Sediment Samples (Shelby Tube)

Sediment Core Site	Sample Designation	Depth (ft)	Volume of Sample (ft^3)	Dry Weight (lb)	Dry Specific Weight (lb/ft^3)
HCS-1	HCS-1A	0-2.4	0.034	2.82	83
HCS-1	HCS-1B	2.4-4.8	0.030	2.98	99
	HCS-1C	4.8-7.2	0.040	3.84	96
HCS-2	HCS-2A	0-2.4	0.030	2.31	76
	HCS-2B	2.4-4.8	0.040	3.06	77
	HCS-2C	4.8-7.0	0.032	3.09	97
HCS-3	HCS-3A	0.3-2.7	0.044	3.61	82
	HCS-3B	2.7-5.1	0.041	3.36	82
	HCS-3C	5.1-7.0	0.027	2.22	82
	HCS-3D	7.0-9.2	.040	3.62	91
HCS-4	HCS-4A	0.0-2.2	0.025	1.96	78
	HCS-4B	2.2-4.4	0.015	1.16	77
	HCS-4C	4.4-6.6	0.025	1.65	87
	HCS-4D	6.6-8.6	0.031	2.15	69[1)]

[1] Plant fragments in sample

Table G-1 (continued)

Specific Weights of Petrolia Reservoir Sediment Core Samples

Hand-cored Sediment Samples (Shelby Tube)

Sediment Core Site	Sample Designation	Depth (ft)	Volume of Sample (ft^3)	Dry Weight (lb)	Dry Specific Weight (lb/ft^3)
HCS-5	HCS-5A	0-2.2	0.037	2.65	72
	HCS-5B	2.2-4.4	0.038	2.49	66
	HCS-5C	4.4-6.6	0.030	2.49	83
	HCS-5D	6.6-7.5	0.019	1.71	90
HCS-6	HCS-6A	0.0-2.3	0.042	2.15	51
	HCS-6B	2.3-4.5	0.042	2.83	68
	HCS-6C	4.5-6.0	0.027	1.79	66
	HCS-6D	7.0-9.0	0.030	1.93	64
HCS-7	HCS-7A	0.0-2.2 (only top .5 is res. sed.)	0.039	3.29	84
HCS-8	HCS-8A	0.0-2.2	0.010	0.62	62[2)]
	HCS-8B	0.4-1.4	0.006	0.22	37[3)]
	HCS-8C	1.4-3.6	0.027	3.50	83

---

2 poor recovery

3 samples 8B and 8C are sequential

Table G-1 (continued)

Specific Weights of Petrolia Reservoir Sediment Core Samples

Raft Sediment Samples (Piston-Corer)

Sediment Core Site	Sample Designation	Depth (ft)	Volume of Sample (ft^3)	Dry Weight (lb)	Dry Specific Weight (lb/ft^3)
RS-1 (RS-2)	RS-1	0.0-3.0	0.072	2.69	37
RS-3	RS-3A	0.0-2.0	0.046	2.74	60
	RS-3B	2.0-4.0	0.046	3.83	83
RS-4	RS-4A	0.0-2.0	0.046	3.12	68
	RS-4B	2.0-4.0	0.046	3.24	70
	RS-4C	4.0-6.0	0.021	3.91	85
	RS-4D	6.0-7.04	0.021	0.428	20[4)]
RS-5	RS-5A	0.0-4.0	0.10	5.66	55
	RS-5B	4.0-6.1	0.051	4.31	85
RS-7	RS-7A	0.0-2.0	0.046	2.86	62
	RS-7B	2.0-4.0	0.046	3.90	85
	RS-7C	4.0-6.0	0.046	3.91	85
	RS-7D	6.0-7.45	0.032	3.16	99

[4] ended on gravel -- poor recovery

Table G-1 (continued)

Specific Weights of Petrolia Reservoir Sediment
Core Samples

Raft Sediment Samples (Piston-Corer)

Sediment Core Site	Sample Designation	Depth (ft)	Volume of Sample (ft^3)	Dry Weight (lb)	Dry Specific Weight (lb/ft^3)
RS-8	RS-8A	0.0-2.0	0.046	2.90	63
	RS-8B	2.0-4.0	0.046	3.26	71
	RS-8C	4.0-6.0	0.046	3.70	80
	RS-8D	6.0-7.42	0.031	1.55	50[5)]
RS-9	RS-9A	0.0-2.0	0.042	2.78	66
	RS-9B	2.0-4.0	0.046	4.05	88
	RS-9C	4.0-6.0	0.028	2.44	87
	RS-9D	6.0-7.1	0.024	2.13	89
RS-10	RS-10A	0.0-2.0	0.044	1.34	30
	RS-10B	2.0-4.0	0.043	1.95	45
	RS-10C	4.0-6.0	0.032	2.39	75
	RS-10D	6.0-7.1	0.022	2.04	93

[5] sample includes root material

Table G-2

Conversion of Sediment Volumes to Weight -
Petrolia Reservoir

WEST ARM
(from Station 3W to 204, West)

Thickness Interval (ft)	Volume of Sediment (acre-feet)	Volume of Sediment (ft^3)	Specific Weight (lb/ft^3)	Weight in Interval (tons)[1]
0-1	153	6.7×10^6	55	1.8×10^5
1-2	88	3.8×10^6	62	1.2×10^5
2-4	60	2.6×10^6	73	9.5×10^4
4-6	4.4	1.9×10^5	84	8.0×10^3
6-8	0.4	1.7×10^4	87	7.4×10^2
8-10	0	--	--	
			TOTAL:	4.1×10^5 tons

[1] accuracy ±20%

Table G-3

Conversion of Sediment Volumes to Weight -
Petrolia Reservoir

SOUTH ARM
(from Station 3-5 to 204, South)

Thickness Interval (ft)	Volume of Sediment (acre-feet)	Volume of Sediment ft^3)	Specific Weight (lb/ft^3)	Weight in Interval (tons) [1]
0-1	151	6.6×10^6	65	2.1×10^5
1-2	130	5.7×10^6	72	2.1×10^5
2-4	180	7.8×10^6	77	3.0×10^5
4-6	100	4.4×10^6	81	1.8×10^5
6-8	40	1.7×10^6	83	7.1×10^4
8-10	7	3.0×10^5	87	1.4×10^4
10-12	0	--	--	
			TOTAL:	9.9×10^5 tons

[1] accuracy ±20%

Table G-4

Conversion of Sediment Volumes to Weight -
Petrolia Reservoir

LOW POOL
(Area between 3-W to 204
and 3-S to 204)

Thickness Interval (ft)	Volume of Sediment (acre-feet)	Volume of Sediment (ft^3)	Specific Weight (lb/ft^3)	Weight in Interval (tons) [1]
0-1	80	3.5×10^6	30	5.3×10^4
1-2	67	2.9×10^6	37	5.4×10^4
2-4	60	2.6×10^6	55	7.2×10^4
4-6	0	--	--	
			TOTAL:	1.8×10^5 tons

[1] accuracy ±20%

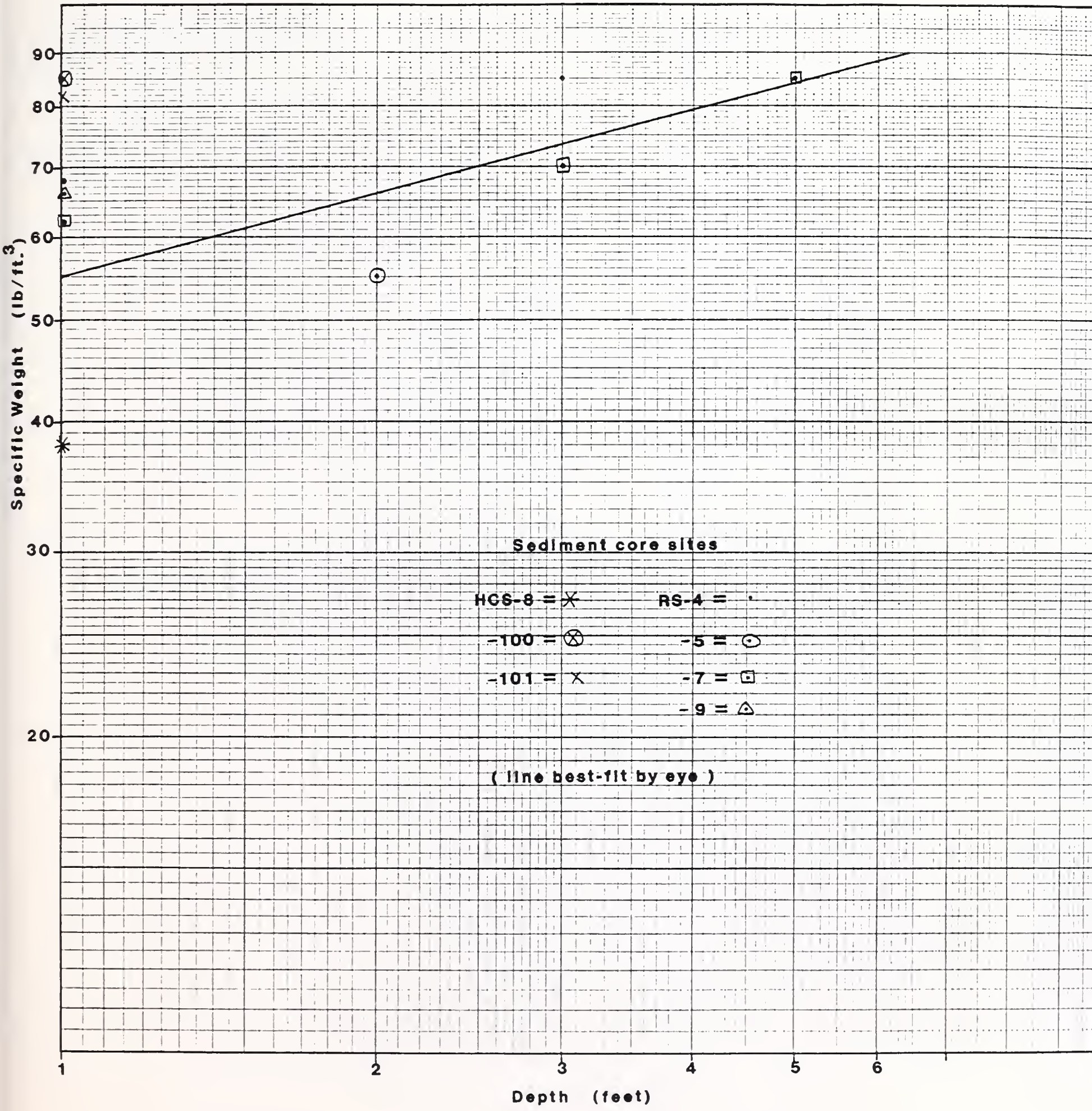


FIGURE G-1. Relation Between Specific Weight and Depth for West Arm, Petrolia Reservoir.

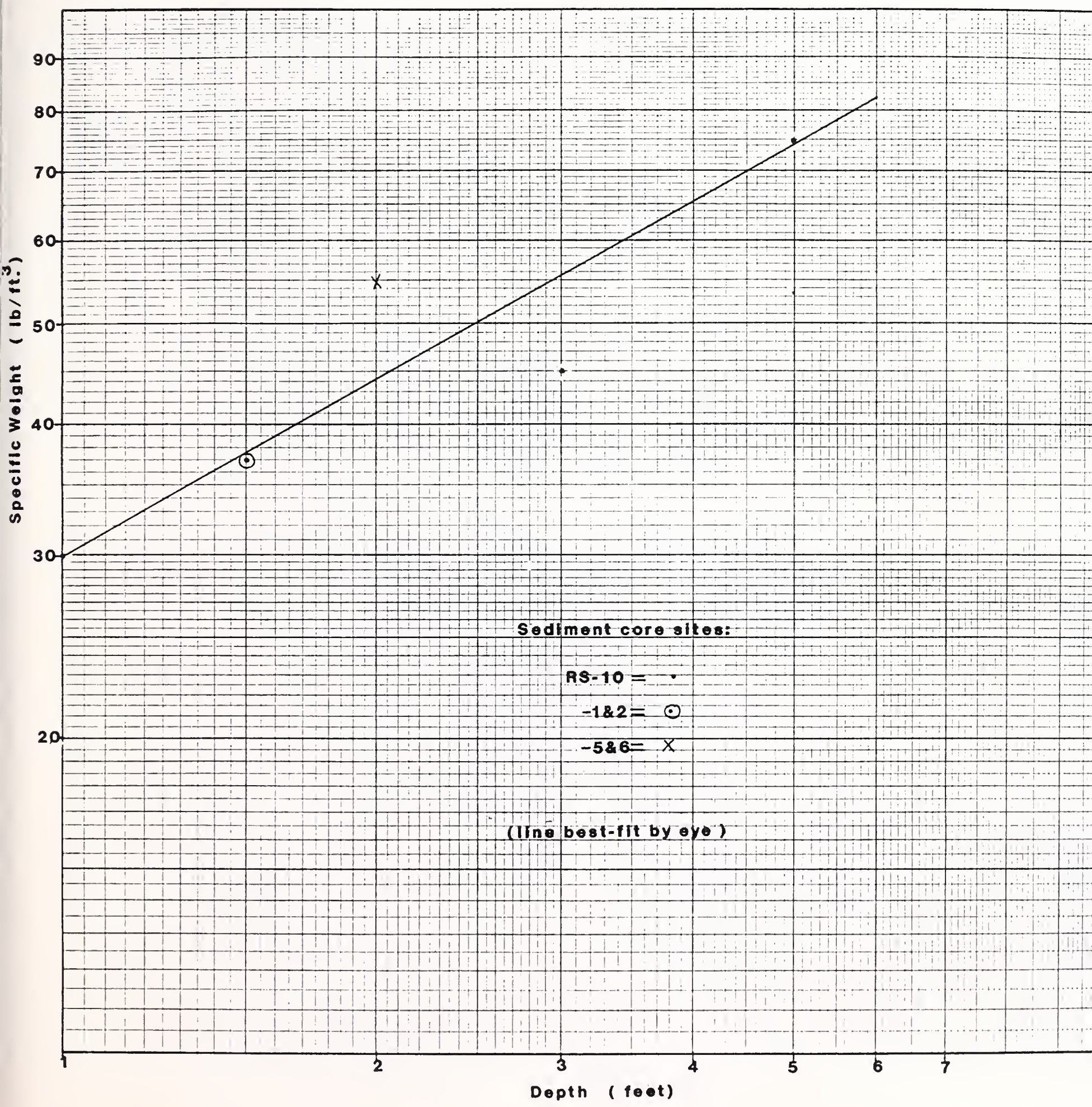


FIGURE G-2. Relationship Between Specific Weight and Depth for Pool Area, Petrolia Reservoir.

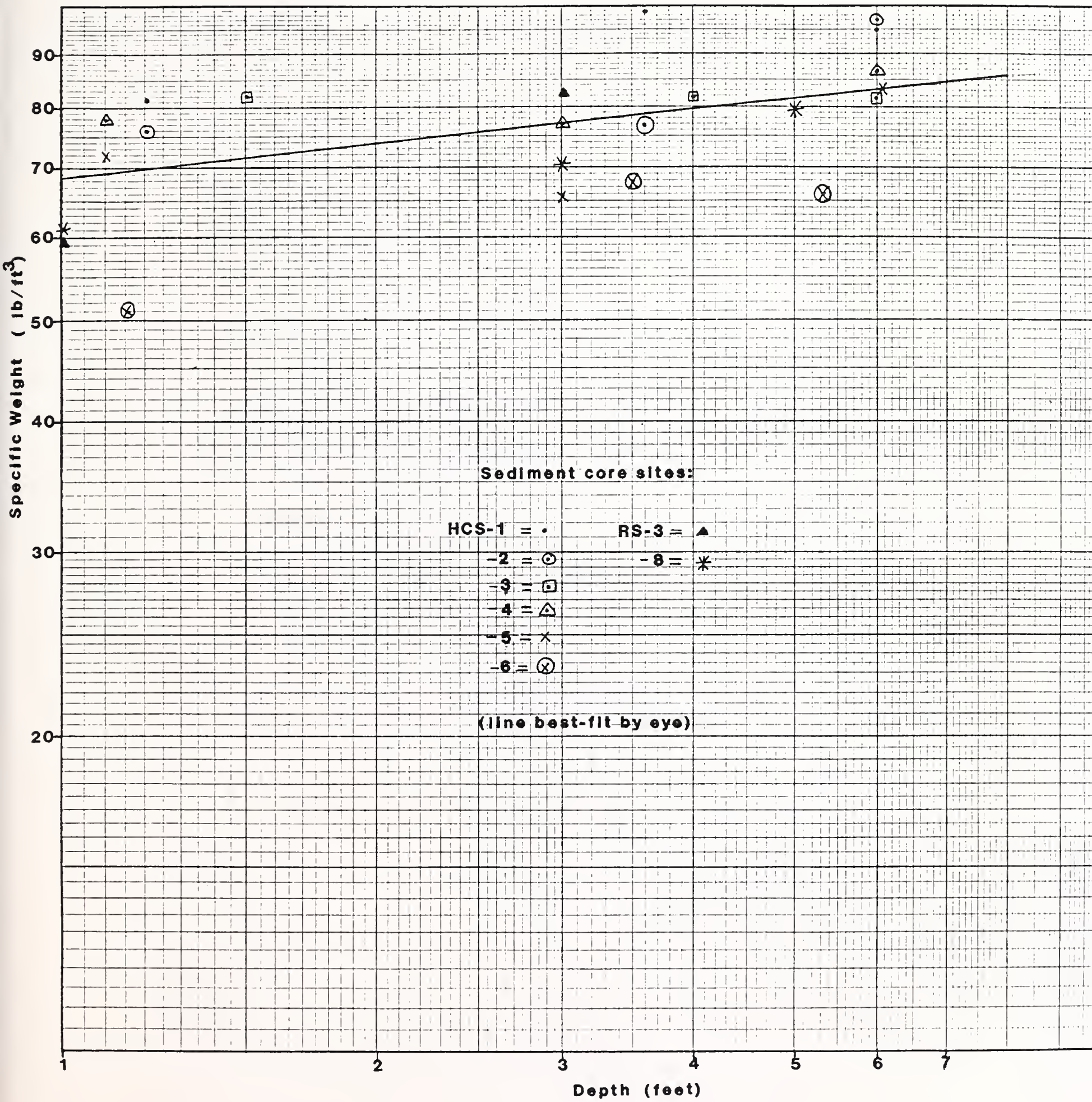


FIGURE G-3. Relation Between Specific Weight and Depth for South Arm, Petrolia Reservoir.

APPENDIX H

ACKNOWLEDGEMENTS

This sediment study of Petrolia Reservoir was done by Streamworks under contract number WE-RLA-156 to the Montana Department of Natural Resources and Conservation, Helena, Montana. The work was done by the following Streamworks personnel:

Robert L. Anderson, P.E., M.S., Water Resources Engineer;

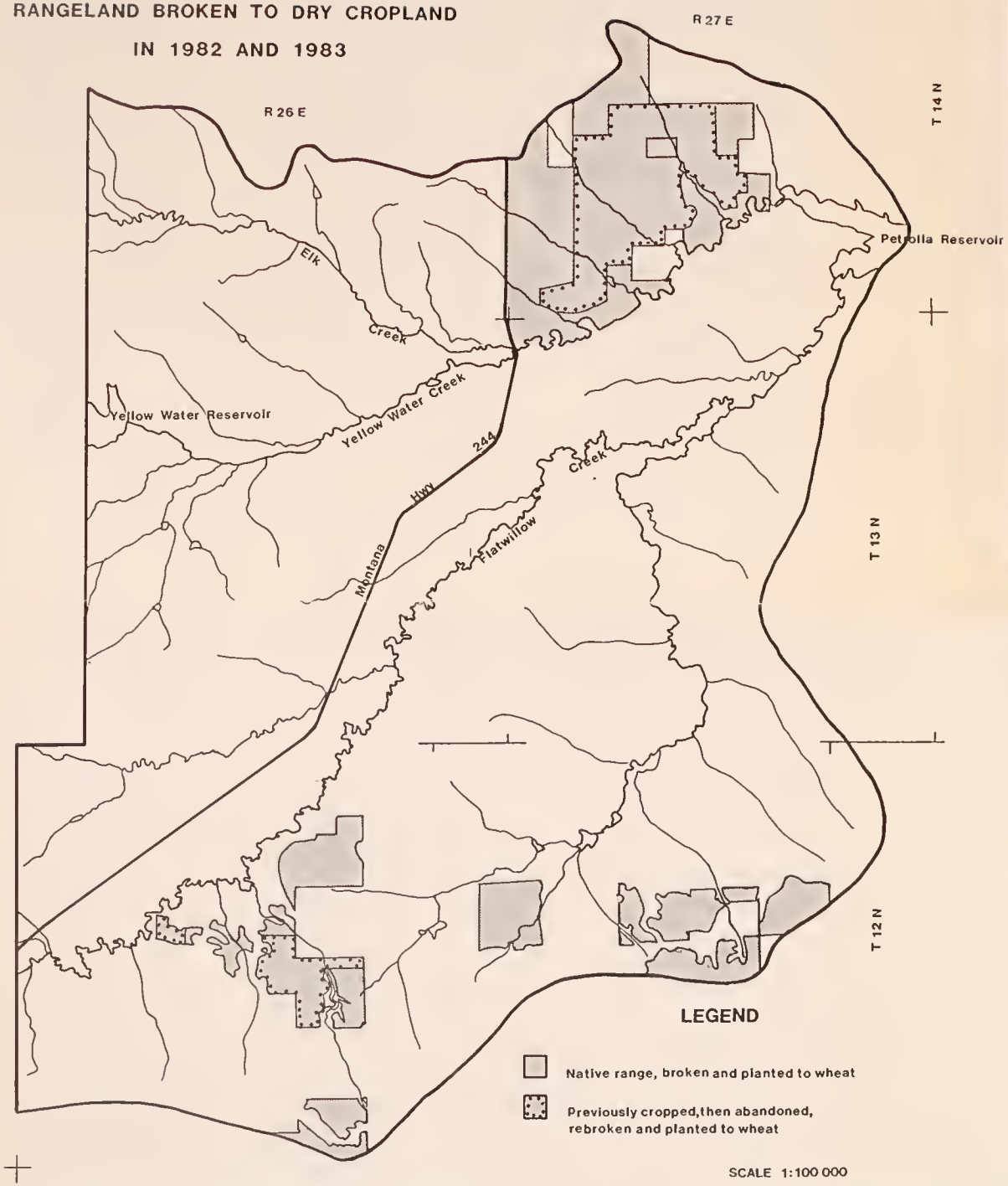
Ray H. Breuninger, Ph.D., Geologist, Streamworks Partner;

Charles Dalby, M.S., Hydrologist, Geomorphologist, Streamworks Partner.

We thank Larry Legg, Larry Donovan, and Jim Sanders for their help in topographic surveying, and Bill McKenzie for piloting the boat during the fathometer survey.

PLATE 6

RANGELAND BROKEN TO DRY CROPLAND IN 1982 AND 1983



Source: Unpublished U.S. Agriculture Stabilization and Conservation Service (Lewistown, Montana) maps compiled from 1983 aerial photographs.

PLATE 1

DRAINAGE BASIN MAP OF FLATWILLOW AND YELLOW WATER CREEKS ABOVE PETROLIA RESERVOIR

Prepared by Streamworks as overlay on Bureau of Land Management 1:100,000 Surface Management Status maps, Big Snowy Mountains (1979) and Musselshell (1978)

MAY 1984
STREAMWORKS
614 Hollins,
Helena, Montana 59601

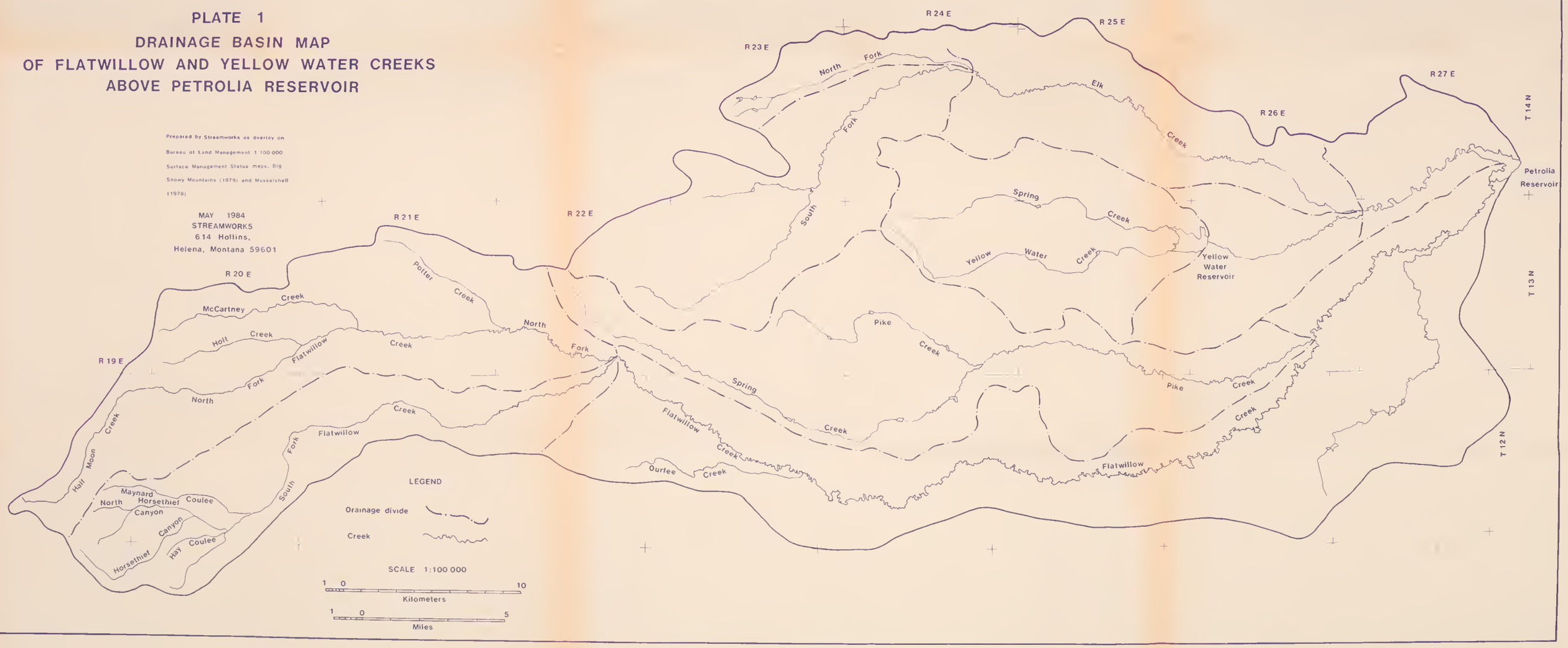
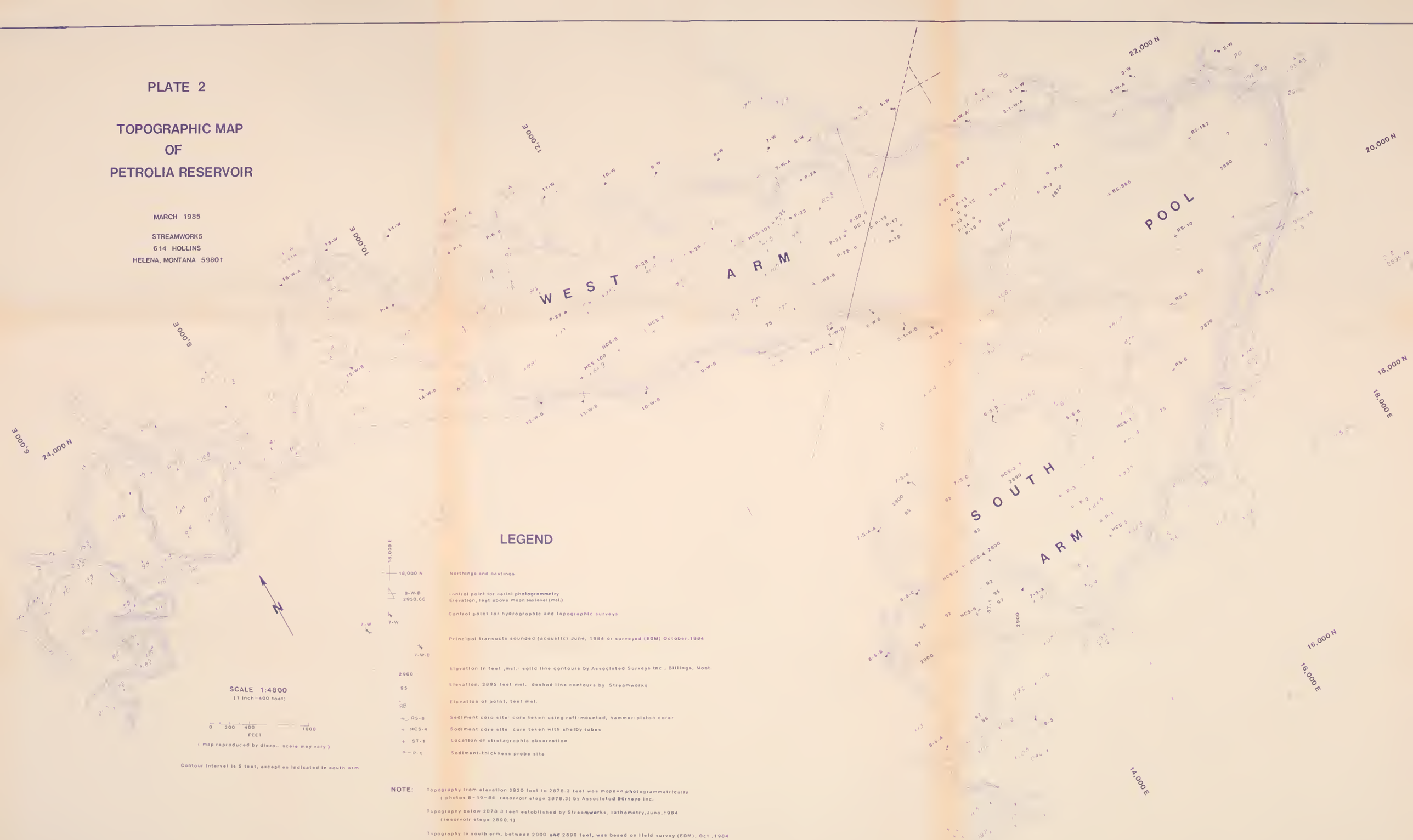


PLATE 2

TOPOGRAPHIC MAP OF PETROLIA RESERVOIR

MARCH 1985

STREAMWORKS
614 HOLLINS
HELENA, MONTANA 59601



LEGEND

18,000 N / 18,000 E	Northings and eastings
8-W-B 2950.66	Control point for aerial photogrammetry. Elevation, feet above mean sea level (msl.)
7-W	Control point for hydrographic and topographic surveys
7-W-B	Principal transects sounded (acoustic) June, 1984 or surveyed (EDM) October, 1984
2900	Elevation in feet, msl.: solid line contours by Associated Surveys Inc., Billings, Mont.
95	Elevation, 2895 feet msl. dashed line contours by Streamworks
	Elevation of point, feet msl.
RS-8	Sediment core site: core taken using raft-mounted, hammer-piston corer
HCS-4	Sediment core site: core taken with shelby tubes
ST-1	Location of stratigraphic observation
P-1	Sediment-thickness probe site

NOTE: Topography from elevation 2920 foot to 2878.3 feet was mapped photogrammetrically (photos 8-19-84 reservoir stage 2878.3) by Associated Surveys Inc.

Topography below 2878.3 feet established by Streamworks, bathometry, June, 1984 (reservoir stage 2890.1)

Topography in south arm, between 2900 and 2890 feet, was based on field survey (EDM), Oct., 1984

PLATE 3

SEDIMENT THICKNESS MAP OF PETROLIA RESERVOIR

Petrolia County, Montana

Scale 1 inch=400 feet

Thickness isopachs: 0 1, 2, 4, 6, 8, 10 feet

Source: Bottom fathometry, and sediment coring and probing done July-August 1984

Prepared by Ray H. Breuninger, Streamworks, 614 Hollins, Helena, MT 59601

PLATE 4

LAND USE MAP
OF FLATWILLOW AND YELLOW WATER BASINS
ABOVE PETROLIA RESERVOIR

Prepared as overlay on Bureau of Land Management
1:100,000 Surface Management Status maps,
Big Snowy Mountains (1979) and Musselshell (1978)
Compiled by Ray H. Breuninger

Streamworks
614 Hollins
Helena, Montana 59601

R 19 E
R 20 E
R 21 E
R 22 E
R 23 E
R 24 E
R 25 E
R 26 E
R 27 E
T 14 N
T 13 N
T 12 N

LEGEND

- Irrigated land :crops, hay, pasture
- Commercial forest
- Non-commercial forest
- Non-irrigated cropland
- Abandoned cropland
- Rangeland

SCALE 1 : 100 000

1 0 10
Kilometers

1 0 5
Miles

PLATE 5

ACCELERATED EROSION AND SALINE SOILS IN THE DRAINAGE BASIN ABOVE PETROLIA RESERVOIR

PETROLEUM AND FERGUS COUNTIES, MONTANA

OCTOBER 1984

Field reconnaissance and interpretation of 1975 aerial photos by Ray Draulinger, 1984
Base map compiled from U.S. Bureau of Land Management 1:100,000 Surface Management Status maps (Big Snowy Mountains, 1979, Musselshell, 1978)

STREAMWORKS
614 Hollins
Helena, Montana 59601

LEGEND

- Vegetative cover generally good; sheet and gully erosion slight; few saline soils
- Accelerated erosion: vegetative cover fair to none, sheet and rill erosion locally severe surface soils mostly clayey, and infiltration rates generally low
- Saline soils: similar to areas with accelerated erosion
- Seepage steps locally present
- Gully erosion locally present
- Earth-fill dam

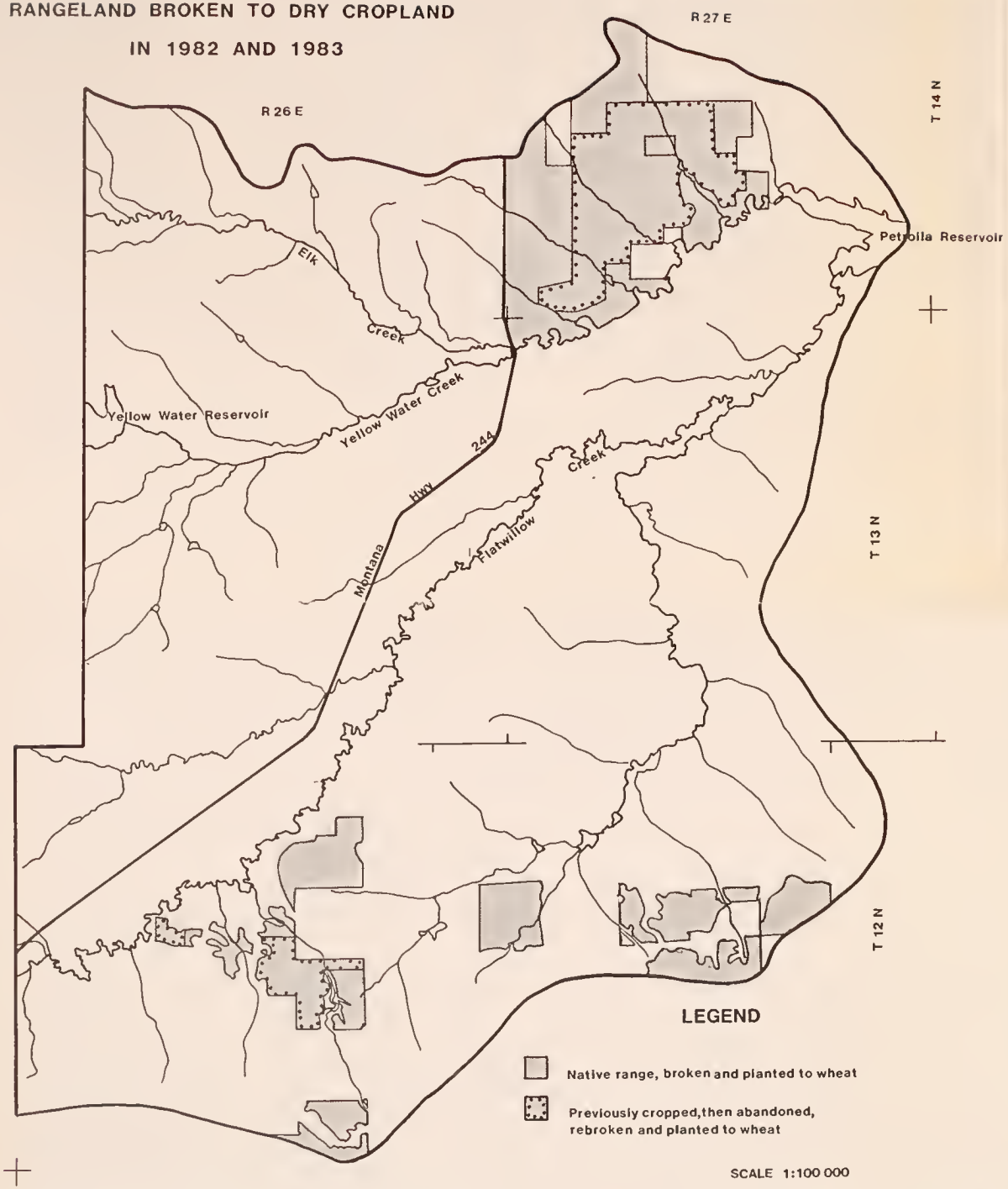
SCALE 1:100 000

1 0 10 Kilometers

1 0 5 Miles

PLATE 6

RANGELAND BROKEN TO DRY CROPLAND IN 1982 AND 1983



Source: Unpublished U.S. Agriculture Stabilization and Conservation Service (Lewistown, Montana) maps compiled from 1983 aerial photographs.